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Natural and mechanical locomotion

One of the characteristic features of the last half-century has been the enormous development in the means and pace of locomotion. A new medium—the air—has been conquered, and the surface mastery of the oceans has been supplemented by the successful elaboration of sub-aqueous navigation. There are now very few conditions under which man is dependent solely on his own muscles for effective transport. It is significant, however, that the aeroplane and submarine, as well as other locomotory inventions, were either inspired by, or based on, principles already well established in the animal world; and it is therefore of interest to compare the results of man's mechanical genius with the products of Nature's own design.

Much work has in fact been carried out during the last few years upon the locomotory activities of animals, and some of the results deserve to be better known. Apart from its intrinsic interest, progress in our knowledge of the way in which animals move may from time to time provide conclusions of real value and enlightenment to the designer of physical machines. A case in point emerges from an analysis of the mechanism of movement of a typical aquatic animal such as a fish or a dolphin. From a combination of cinematographic and wind-tunnel observations the principles whereby such animals propel themselves through the water and maintain a steady line of movement are known with considerable accuracy. It is possible, therefore, to make at least an approximate comparison of the performance of, say, a dolphin with that of a submarine or torpedo. The resulting data prove to be of very wide general interest.

The maximum under-water speed of a modern submarine is, of course, known to comparatively few people, but it is certainly a great deal less than that of a dolphin. Estimates of the sustained speed attained by the latter have occasionally been exaggerated, but well-authenticated evidence shows that a specimen six feet in length can maintain a minimum speed of 20 knots for long periods of time without showing signs of fatigue. To drive a full-scale rigid model through water at this speed requires about 2½ h.p.; and since the total weight of the muscles operating the body of the dolphin is about 33 lb. it would appear that the horse-power per pound of muscle is roughly 0·07. Now the corresponding figure for the muscles of a very highly trained athlete or dog never exceeds about 0·01, even if the output of work is restricted to a period of time far shorter than that taken in the case of the dolphin. Hence it must be concluded either that the muscles of a dolphin are some seven times as efficient as those of other mammals, or that the resistance of the water to the movement of the dolphin is very much less than to the movement of the rigid model.

The first alternative seems highly improbable, for it would imply the use of an abnormally large quantity of oxygen and the dissipation of heat at an extremely rapid rate through a thick layer of fat. If, on the other hand, it is assumed that the dolphin develops a normal mammalian horse-power per pound of muscle, its total available output would be 0·3 h.p.; and this would suffice to drive the animal through the water at 20 knots if the resistance were about one-tenth of that encountered by the rigid model. This low level of resistance would be possible only if the flow of water past the body were perfectly smooth and did not involve a wastage of energy comparable with that due to the large eddies characteristic of the flow past the rigid surface of the model. During the animal's motion, the whole surface of the body is constantly being deformed by the undulatory movements which form an essential part of the locomotory mechanism, and the

possibility that these undulations may be the means by which eddy formation is eliminated is suggested by recent observations on the flow of water past the bodies of fish. Similarly indicative is the fact that when a dolphin is swimming in a medium which is itself phosphorescent only when turbulent, the outline of the body is very sharply defined as a phosphorescent surface: there is no evidence of large eddies. If this preliminary work is substantiated by further research, the possibility of endowing a submarine or torpedo with an actively undulating surface will provide an interesting field for speculation and engineering skill.

In the range of aerial movement, the comparison between a bird or an insect and an aeroplane is obvious. So long as a bird is gliding, the whole animal is strictly comparable with a glider aeroplane—with one important difference. In the case of the glider, the aerofoils and rudders are rigid, whereas in the bird the all-important feathers are highly flexible. This renders the wing virtually unstallable and endows the bird with very remarkable powers of manœuvre. When flying under power, the action of a bird's wing is highly complex, for it represents both the wing and the airscrew of an aeroplane combined into a single unit. Further, whereas the speed of flow from the airscrew is more or less steady, the flow past the oscillating wings of a bird is extremely variable and complex. At the beginning and end of each half-cycle of oscillation the wing is at rest, but at intermediate positions the velocity is surprisingly high. For example, the rate of movement of the tip of a pigeon's wing during quite slow and deliberate flight is of the order of 60 m.p.h., and it reaches this speed within one-twentieth of a second after starting from rest.

In order to observe such movements adequately, spark photography is essential; but by the use of suitable apparatus a relatively complete picture has now become available of the whole cycle of wing-beats. This makes it clear that the flexibility of the individual feathers, and of the wing as a whole, plays a very vital role in the maintenance of steady flight. The general impression derived from the work suggests that the mechanism of bird flight would be appropriate only for relatively small animals travelling at speeds not substantially higher than 60 m.p.h. It is, however, associated with a power of manœuvre far in excess of that of any aeroplane.

To glance briefly at another natural and mechanical parallel, it may be remarked that the movements of the snail and of the caterpillar tractor are based on closely similar principles. In both cases the essential feature of movement is the maintenance of a relatively large and stationary bearing surface on the ground. The way in which this condition is fulfilled in the snail has recently been studied. It provides an interesting example of Nature's achievement of the same end as man, although the individual components of the machine are entirely different in the two cases.

To some extent, Nature is more versatile than man in the use of fundamental principles. For instance, she not only effectively employs jointed levers in the limbs of most vertebrates but, in the case of the gliding of a snake, uses a principle so far completely neglected by the human inventor. The progression of snakes was to Solomon one of the three most inscrutable phenomena, but it is in fact fairly simple. It depends upon the ability of the animal to press the sides of its body into contact with three or more external objects and to adjust its shape to such a form that there is always a backward pressure against the points of contact.

In general it may be said that Nature's mechanisms differ from those of man in two fundamental characters. Firstly, Nature almost invariably employs flexible rather than rigid material for the construction of component parts. Secondly, she does not employ the principle of the wheel and axle. Relatively high speed movements in an animal depend on the ability of muscles to produce extremely rapid acceleration of the various oscillating parts, and the dangerous strains involved must be guarded against by safety devices built up from flexible elements. Except in under-water conditions, animals cannot compete with man's inventions as far as speed is concerned—but in respect to powers of manœuvre Nature is always an easy winner.

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Chemistry of the Australian Bush

JOHN READ

Australia, 'the land of the eucalypt and the kangaroo,' has a flora that is at once strange and unique. Very much of the vegetation consists of members of the natural family *Myrtaceae*, of which Europe possesses only one indigenous species. Professor Read discusses some of the interesting botanical, phytochemical, and chemical problems presented by Australian plant life, and pays tribute to the pioneer work of R. T. Baker and H. G. Smith.

A STRANGE FLORA

From its discovery onwards, Australia has appealed to the outside world as the habitat of a strange flora and fauna. Multitudes who have never been remotely 'within coo-ee' of the great southern continent picture it to themselves as the land of the eucalypt and the kangaroo. A great deal lies behind this popular conception of Australia. The eucalypt and the kangaroo are vivid symbols of a unique flora and fauna; more than that, in some degree they are typical survivals into the present age of an order of living things inherited from a remote epoch, and elsewhere obsolete or non-existent. This ancient order, seemingly unchangeable or developing in a unique manner in its isolated Australian environment, has stamped its impress as deeply upon the indigenous plant products of Australia as upon visible characters of the parent flora.

Captain William Dampier, in 1688, mistook the eucalypts of north-western Australia for 'Dragon-trees,' and later Europeans to reach Australia could not fail to notice the strange appearance of the trees, shrubs, and flowers which confronted them. The first detailed record of such an impression is of great historic interest, for it may be traced back to Captain James Cook's original landing from his barque *Endeavour* on the eastern coast of Australia, on 20th April, 1770. On Sunday, 6th May, Cook wrote in his journal (now in the Mitchell Library, Sydney): 'The great quantity of this sort of fish found in this place occasioned my giving it the name of *Stingray Harbour*.' Before the *Endeavour* reached Batavia, however, he had changed the entry to: 'The great quantity of New Plants, etc., Mr. Banks and Dr. Solander collected in this place occasioned my giving it the name of [*Botanist* corrected to] *Botany Bay*.'

Mr (later Sir Joseph) Banks described (3rd May) how he carried ashore at Botany Bay 'all the drying paper, nearly 200 quires, of which the larger part was full, and spreading them upon a sail in the sun, kept them in this manner exposed the whole day.' In the following month his specimens were soaked with sea-water as a result of the historic accident near the Endeavour River; but they are still extant in good condition —many of them were presented by the Trustees of the British Museum to the National Herbarium at Sydney in 1904.

The strangeness of the indigenous flora of Australia to the European visitor arises from the fact that so much of this vegetation belongs to the *Myrtaceae*, a large family of which Europe claims only a single species in the sweet-scented myrtle of the poets (*Myrtus communis*). In Australia, there are more than eight hundred species of *Myrtaceae*, a number exceeded only by the much less conspicuous *Leguminosae*, with some thirteen hundred species. Of the forty-five genera of *Myrtaceae* represented in Australia, the most important is *Eucalyptus* [14]. This genus is a highly specialized form of myrtaceous plants, developed in great profusion probably after the separation of Australia from the great tropical lands and adapted to its xerophilous and more barren environment [14]. Among other myrtaceous genera occurring in Australia are *Myrtus*, *Eugenia*, *Angophora*, *Backhousia*, *Melaleuca*, *Leptospermum*, and *Darwinia*. The last three of these genera are shrubby, the others, like *Eucalyptus*, mainly trees. All of them except *Myrtus* and *Eugenia*, which bear fleshy berries, have dry fruits. Myrtaceous genera with dry fruits are chiefly Australian, but a few representatives are found in New Guinea, Celebes, New Caledonia with neighbouring islands, and New Zealand. The shape and size of the fruits are important in the identification of *Eucalyptus* species. The indigenous occurrence of the genus *Eucalyptus* is mainly confined to Australia, New Guinea, and Celebes, but suitable

species are now cultivated extensively in many other countries, ranging from New Zealand to California, South Africa, and the Mediterranean region, mainly as timber trees of exceptionally rapid growth, and for their beneficial effect when planted in marshy land. For example, near Rotorua, New Zealand, *E. oreades* readily grows to a height of 120 ft. in thirty years.

THE EUCALYPTUS OIL INDUSTRY

Although the biochemical features of living organisms are much less obvious than their morphology, yet the earliest settlers in Australia quickly became aware of the richness of the trees and shrubs of the 'Bush' in fragrant oils and also in resinous exudations. The latter products, so common among eucalypts, were mistakenly called 'gums,' and the name was transferred to the trees themselves. The timbers of numerous species of *Eucalyptus* are deservedly held in much esteem [1]; but chemically the greatest interest of this premier genus of Australia lies in its essential oils.

These oils are secreted in minute, semi-transparent leaf-glands, which may be seen when a leaf is held up to the light; sometimes, too, a similar oil is found in the bark and wood. Essential, or essence-like, oils possess fragrant odours, as the name indicates. They are more mobile and more volatile than the 'fixed' plant oils, such as linseed, cotton-seed, coco-nut, and olive oils; unlike these oils, they are not of a fatty nature, and are unassimilable. Their high inflammability is largely responsible for the fierceness of Australian bush fires. Besides *Eucalyptus*, the other myrtaceous genera already mentioned are also lavish sources of essential oils, and so are many other native Australian plants belonging to the *Coniferae*, *Rutaceae*, *Labiatae*, and other families. Thus the essential oil industry, which grew up in Australia around the eucalypts, has gradually extended to embrace many species in other genera and families of indigenous plants.

Of all such oils, those of the eucalypts are by far the commonest and the most important. The story of the first distillation of an Australian essential oil is bound up with Dr John White, Surgeon-General to the First Settlement. He went out with Governor Phillip, who reached Botany Bay with his fleet of marines, officials, and convicts on 20th January, 1788. The voyage from England, by way of Rio de Janeiro and the Cape of Good Hope, took more than eight months, and is described with much interesting detail in White's *Journal*, dated from Sydney Cove, Port Jackson, New South Wales, 18th November, 1788 [9] [15].

Soon after the incipient colony had moved from Botany Bay to Port Jackson, White ran out of oil of peppermint, which was much prized in those days as a specific for 'gouty and cholicky pains' and 'disorders arising from wind.' The surgeon-general and his assistant, Consiaden, found an efficient substitute in the oil distilled from the leaves of a tree growing on the shores of Port Jackson. The statement in an Appendix to White's *Journal* [15] runs as follows:

> The name of Peppermint Tree has been given to this plant by Mr. WHITE on account of the very great resemblance between the essential oil drawn from its leaves and that obtained from the Peppermint (*Mentha piperita*) which grows in England. This oil was found by Mr. WHITE to be much more efficacious in removing all cholicky complaints than that of the English Peppermint, which he attributes to its being less pungent and more aromatic.

The Appendix to White's *Journal*, containing an illustrated account of the flora and fauna of the new land, includes a drawing entitled 'The Peppermint Tree.' This species is now known as *Eucalyptus piperita*, or the Sydney Peppermint, and is common around Sydney and in the Blue Mountains of New South Wales.

It is often supposed that 'eucalyptus oil' is a standard material consisting mainly or wholly of eucalyptole, otherwise known as cineole, the odour of which is disseminated so freely from handkerchiefs during epidemics of colds or influenza. The term 'eucalyptus oil,' however, is a vague one with no precise meaning. In fact, each species of *Eucalyptus*—of which more than three hundred[1] are known—has its own distinctive oil, and each oil is a complex mixture of constituents. White's original eucalyptus oil, as we have seen, had an odour of peppermint and not of eucalyptole. The odours of eucalyptus oils range indeed over a wide gamut, including turpentine, eucalyptole, peppermint, lemon, and geranium among its dominant notes.

These oils and their numerous ingredients have been applied in many ways. The original uses of eucalyptus oils were medicinal. For such purposes the oil of *E. globulus*, or Blue Gum,

[1]The number of *Eucalyptus* species recognized by different investigators varies over a wide range, up to a maximum of some five hundred. There are also considerable variations in the nomenclature of the genus: for the purposes of this account it has proved simplest to adopt the nomenclature of Baker and Smith [2].

formerly took first place; but eventually this was replaced by cineole oils of the same general character obtained from species producing higher yields of oil. Thus, the leaves and twigs of *E. globulus* furnish less than 1 per cent. of oil, a yield which is doubled in *E. polybractea* and nearly quadrupled in *E. australiana*. These three oils are rich in cineole, and are used mainly as mild disinfectants or germicides. This useful property is exhibited in different degrees by many other eucalyptus oils, and is not peculiar (as was formerly supposed) to those containing cineole. The first factory for the extraction of eucalyptus oils was started in Victoria by Bosisto in 1854. As the oils from various species became better known, some were found to be of value for perfumery, some for use in special processes such as the 'flotation' process for concentrating ore, and some for the manufacture of fine organic chemicals. Eventually, therefore, the distillation of eucalyptus oils grew into an important Australian industry.

This industry literally has its roots in the Australian bush, and in favourable localities the oil distillers' camps with their batteries of crude stills are a familiar sight. In travelling along a bush track in such a region one may traverse a natural forest of eucalypts of many species. In age, these may range from seedlings a few inches high and a few months old to monarchs of the forest dating back before the days of Captain Cook and the First Settlement. Among them, in a particular district of New South Wales, may be seen gigantic Bloodwoods (*E. corymbosa*), distinguished by their rough scaly bark, of warm red hue, and long dark dribbles of exudation; clean-limbed Peppermints (*E. phellandra*), with narrow leaves and delicately latticed bark; lofty White Stringybarks (*E. eugenioides*), with the characteristic ridged bark, fibrous and intertwining; graceful Gully Ashes (*E. smithii*), grey-limbed with long pendulous leaves; and many others.

Such eucalyptus species are strongly individualistic in appearance. They may be trim eucalypts, with bark persistent on trunk and branch; unkempt eucalypts, with bark partly adherent and partly shed; dishevelled eucalypts, waving long barky tresses in the breeze; stark eucalypts, spreading white arms wide against the cloudless blue of an Australian sky; spotted eucalypts; sombre eucalypts; silvery eucalypts; and eucalypts of still other types, in bewildering variety. Between their boles, in this New South Wales district, a luxuriant scrub grows in profusion: many species of leptospermum, with small sweet-scented leaves; feathery, dark-green wattles; stiff-leaved banksias; slender-stemmed waratahs; soft-petalled flannel flowers, reminiscent of edelweiss—new species at every turn illustrating the richness and strangeness of the bush vegetation in this region of Australia [7].

The ecology of the eucalypts is of great interest. The species differ greatly in kind according to soil, altitude, climate, and other environmental conditions. In the natural distribution of the genus, each region thus possesses a characteristic selection of species adapted to the locality in which they grow. In general, it is unusual to find a eucalyptus forest composed exclusively of one species; for, with the exception of *E. phellandra* and a few other species, the gregariousness of the eucalypt is generic rather than specific. Eucalypts vary in size from small shrubby 'mallees' to giant forms like the noble *E. regnans*, which, in Gippsland, has been known to exceed 300 ft. in height, with a girth of nearly 70 ft. The large trees occur chiefly in regions having a sandy soil poor in mineral constituents, of which they store only a minute amount (0·025 to 0·05 per cent.) in their timber: this peculiarity has been advanced as a prime factor affecting their growth to such great dimensions.

The suitability of a species as a commercial source of oil depends upon the composition and yield of the oil; also, for naturally growing trees, upon the accessibility of the species. The average yield of oil furnished by the mature leaves and terminal branchlets ranges from about 3·5 per cent. in *E. australiana* and *E. phellandra* to 0·06 per cent. in *E. corymbosa*, and dwindles to mere traces in still poorer species. In the harvesting of eucalyptus leaves for distillation, the trees may either be lopped or felled; although felling may appear extravagant, it is often favoured by experienced distillers. When the tree is cut within a foot or two of the ground, a strongly foliaceous 'sucker growth' soon appears, and this may be cut again and again without destroying the reproductive capacity of the tree. The phoenix-like eucalypt conforms to the general motto of the Australian flora, which is '*Resurgam!*' It combines amazing vitality with unusual rapidity of growth in favourable conditions; thus, after the lapse of a couple of years, the decapitated stump may have surpassed the ideal of Dean Swift by producing not merely two, but three, or even four, sturdy stems where only one grew before.

The scrub of Blue Mallee (*E. polybractea*) in the Wyalong district of New South Wales is sometimes treated still more severely. Mallees are dwarf eucalypts having a bunchy growth of small stems springing from a root-crown. In western New South Wales, and also in South Australia and other regions, mallee eucalypts cover large areas. One of them, *E. oleosa*, stores water in its roots, a beneficent provision which was appreciated by the Australian aborigines. Three mallees in particular yield excellent cineole oils: besides the Blue Mallee of New South Wales, these are *E. odorata* and *E. cneorifolia*, from which the bulk of South Australian eucalyptus oil is distilled; the last-named species occurs chiefly on Kangaroo Island.

In dealing with the Blue Mallee, the distiller flattens and partly uproots the scrub by driving a heavy roller over it, and after the roughly treated vegetation has dried in the strong sun he completes its seeming destruction by burning it off. The bare waste which repels the eye at this juncture seems to lack any germ of life. *Resurgam!* In a short time the irrepressible eucalypt reappears: a pleasing dull blue mantle of *E. polybractea* covers the landscape; and after a twelvemonth the distiller's faith is justified by the sight of a luxuriant growth of mallee rising waist high.

The harvesting of the leaves is simpler from mallees than from trees, but the remaining operations are the same for material from either source. In order to liberate the oil, the leaves are brought into contact with steam: this bursts the oil-glands and causes a slow vaporization of their contents. The crude field-still consists of a cubical iron tank with a capacity of 400 gallons, corresponding to about 800 lb. of material when fitted for open firing. The tightly packed leaves rest upon a grating, below which water is boiled by means of a wood fire beneath the tank. As the steam forces its way up through the mass of leaves it becomes charged with the vaporized oil, and the mixed vapours are condensed during their passage through a water-cooled exit tube. The liquid mixture of water and oil runs down into a receiver which is so constructed as to allow the relatively small layer of oil to be drawn away from the water on which it floats. In the more refined types of distilling plant, steam is generated in an independent boiler and passed under pressure into a series of digesters, these being sometimes sunk into the ground in order to facilitate the handling of the fresh and spent leaves. The procedure now outlined is not restricted to the winning of eucalyptus oils: it may be applied generally in the separation of essential oils from plant materials, provided that the chemical constituents are not damaged by steam.

There are many cineole-bearing species, and the reputation of the cineole oils has suffered in the past owing to occasional confusion in the field. A vernacular name, such as Messmate, may be interpreted in various ways, according to local opinion; hence, many years ago, reliable distillers began to adopt the systematic latinized names. The use of scientific nomenclature 'out back' in the Australian bush may cause surprise; yet—as a 'bushwhacker' once remarked, in somewhat different words—there is nothing inherently difficult in the pronunciation of *Eucalyptus macarthuri*, and the name is decidedly more euphonious than the synonymic 'Camden Woollybutt' or 'Paddy's River Box.' In this and many other respects the bush distiller is eminently adaptable and full of resource. Let us take a backward glance at him in a primitive gunyah near Wingello: he is sitting on a kerosene tin before a packing-case, making shift to answer a business letter. He dips his quill into home-made charcoal ink, and writes in the dim light of a primitive lamp: this, too, has been made on the premises, and it burns the home-distilled oil of *E. macarthuri*. 'Greenhide and stringybark are the backbone of Australia!' he murmurs, gazing at his humble bark roof, as he quotes a saying familiar to the early pioneers to whom he is so closely akin in spirit. He is indeed a virile and picturesque Australian type, full of first-hand knowledge mingled with the lore of the bush.

CHEMICAL CHARACTERISTICS OF EUCALYPTS

It is now time to sketch in the scientific background of the eucalyptus oil industry. The first chemical investigation of such an oil was carried out by Cloëz in 1870: this French chemist obtained an impure specimen of cineole by fractionally distilling the oil of *E. globulus*. Since that time numerous investigators, in Australia and elsewhere, have gradually unfolded the fascinating chemistry of the Australian flora. At the present day, in the genus *Eucalyptus* alone, the essential oils of some two hundred species have been examined chemically.

So interwoven are the relationships in this genus, so refined the specific distinctions, that effective studies could be prosecuted only through the combined efforts of the botanist and the

organic chemist. Happily such a collaboration was forthcoming. In 1895, H. G. Smith (1852–1924) published, in collaboration with J. H. Maiden, the distinguished Australian botanist, his first original contribution to organic chemistry, in the form of a paper dealing with eucalyptus kinos, or resinous exudations. In the same year, R. T. Baker (1854–1941) became Curator of the Sydney Technological Museum, where he acted also as Economic Botanist; and in 1899 Smith was appointed Assistant Curator and Economic Chemist at the Museum. The two colleagues entered into an enthusiastic collaboration, and from that time until their retirement in 1921 carried out at the Museum a classical series of botanico-chemical investigations on the Australian flora. Baker and Smith were both born in Kent, England, and made their ways separately to Sydney in the early eighties; they were pioneers of scientific investigation in a new country, and it is remarkable that both of them were largely self-educated for their main life-work. Handicapped in various ways, and receiving less scientific recognition and material reward than could have been desired, they were animated by the spirit which inspired Scheele, of whose life and work Smith was a great admirer: 'The elucidation of new phenomena is my sole concern,' wrote Scheele to Gahn in 1774, 'and how happy is the investigator when the final success of his struggles brings joy to his heart.'

The researches of Baker and Smith on the genus *Eucalyptus* were published at Sydney in 1902, with a revision in 1920 [2]. These researches on the essential oils of numerous species, representative of the Australian mainland and of Tasmania, showed that altogether the genus elaborates more than forty distinct chemical constituents of such oils, of which about half owed their first recognition in eucalyptus oils to Smith. Most of these substances are hydrocarbons or oxygenated derivatives belonging to the terpene series, such as pinene, phellandrene, limonene, cineole, piperitone, eudesmol, geraniol, citral, and citronellal; in addition, there are aliphatic and aromatic constituents. Some of them are peculiar to the Australian flora, which also provides the most abundant source of some of the others.

Each oil contains a certain selection of these constituents in fairly definite proportions, and is thus distinctive for the species. The composition of the leaf-oils appears to remain sensibly unchanged in eucalypts cultivated outside their natural Australian habitat [4]. The yields of oil may be increased considerably by cultivation. Baker and Smith concluded that *Eucalyptus* species may be characterized chemically as well as morphologically. More remarkable still, they were sometimes able to discern a chemical distinction between closely related species, or varieties, when no decisive morphological distinction was apparent. For example, they founded the species *E. phellandra* almost wholly on chemical evidence: 'the economic importance of separating this species from *E. australiana*,' they wrote in 1920, 'can be judged from the fact that at the present time the value of the oil of the latter species is more than double that of *E. phellandra*.'

This quotation illustrates the dual significance of Baker and Smith's collaborative researches, in which the latent economic possibilities were no less important than the immediate scientific advances. The full value of *Eucalyptus* oils as sources on a vast scale of many fine organic chemicals gradually became evident. The crude oil of a good cineole-bearing species, such as *E. polybractea* or *E. smithii*, may contain more than 80 per cent. of cineole, which separates readily (especially from the 'first-hour oil' of the distillation) as a glacial crystalline mass when the oil is cooled in an ammonia refrigerator. *E. dives* oil, when fractionally distilled, may yield about 50 per cent. of piperitone and 40 per cent. of phellandrene: thus it becomes a potential source of such related substances as thymol and menthol. The oil of *E. macarthuri*, containing some 75 per cent. of geranyl acetate, together with a little free geraniol, offers an abundant source of this valuable ingredient of perfumes; this oil contains in addition the much rarer eudesmol, a sesquiterpene alcohol. In New Zealand, where this species is valued also for general and farming purposes, it is grown in extensive plantations around Rotorua.

The crude oil of *E. citriodora*, the 'citron-scented gum' of North Queensland, consists almost wholly of citronellal (90 per cent.); and another Queensland species, *E. staigeriana*, yields a lemon-scented oil containing about 16 per cent. of citral. This oil played a part in one of H. G. Smith's most spectacular demonstrations of the value of Australian plant products for everyday purposes [8]. On the occasion of a formal dinner famous in the annals of the Royal Society of New South Wales, Smith smuggled into the menu an alleged sago pudding flavoured with lemon, which, during his after-dinner speech, he divulged to have been

made under his supervision from the starch of the Burrawang 'Palm' (*Macrozamia spiralis*), flavoured with the leaf-oil of the 'lemon-scented ironbark' (*E. staigeriana*). Fortunately, the effect of this *tour de force* upon the Fellows was more agreeable than the sequel to Basil Valentine's much earlier but fundamentally similar experiment with an antimonial preparation upon the monks of St Peter of Erfurt! [10].

Baker and Smith's generalizations from this joint work are remarkably interesting. They concluded that the oil from any *Eucalyptus* species growing under natural conditions maintains a comparatively constant composition; that each chemical constituent increases in amount through a sequence of species until it reaches a maximum in one or more of them; and that a connexion exists between certain morphological characters, notably the type of venation of the mature lanceolate leaves, and the chemical nature of the oil. A 'feather' venation (as in *E. corymbosa* and *E. calophylla*, the 'red gum' of Western Australia) denotes the presence of pinene and possibly of bornyl acetate (Group I); an intermediate venation (as in *E. globulus*, *E. smithii*, and *E. polybractea*) is a sign of the occurrence of pinene with cineole (Group II); and a 'butterfly-wing' venation (as in *E. piperita* and *E. dives*) points to phellandrene and possibly piperitone or geranyl acetate (Group III).

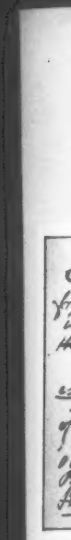
Thus, a large number of *Eucalyptus* species fall into one of three main groups, of which the chemical characteristics may be deduced from a mere inspection of the leaf-venation [11]. This is a startling conclusion, suggesting *inter alia* a revival of the mediaeval doctrine of signatures [10], according to which 'the president of *Nature*' conveyed valuable information to man by insculping 'notable and marvelous *Figures* upon *Plants* . . . and other inferior *Bodies*.' This idea may be carried still further with certain species. For example, *E. gullicki* and *E. haemastoma*, sometimes found growing side by side, are much alike in the field, being trees of medium size with a smooth, white bark. Both the venation of the leaves and their odour, when crushed, indicate, however, that *E. gullicki* secretes cineole (Group II) and *E. haemastoma* phellandrene (Group III). More than this, the latter species, which is known also as Scribbly Gum, almost always shows insect markings, resembling scribbles, on the bark, while *E. gullicki* is innocent of such markings. *E. punctata* and certain other species exude warty masses of 'eucalyptus manna' from insect punctures in the bark and leaves: this curious product consists of a sugar, raffinose.

AN EVOLUTIONARY THEORY

A larger outcome of these phytochemical researches, which embraced the detailed examination of other botanical and chemical features (including the morphology of anthers and cotyledons, the colours of timbers, and the chemical nature of exudations), was Baker and Smith's development of an evolutionary theory, dealing with a geographical and chronological sequence in the genus *Eucalyptus* [2]. There is evidence that the genus may have occurred in Tertiary, or perhaps Cretaceous, times in the northern hemisphere; but Baker and Smith's theory relates only to Australia. According to this theory, the genus perhaps originated in north and north-west Australia, none but the oldest species being found in this region: these belong to Group I, and have 'feather'-veined leaves yielding a maximum of about 0·5 per cent. of a pinene oil. Chemical evolution is held to have accompanied botanical evolution. As the genus spread slowly eastwards and southwards, the evolution of new species was determined by changing conditions of soil and climate, and the pinene-cineole oils of Group II made their appearance. At the end of the evolutionary scale, the most recent species—those of Group III—occur only in south-east Australia and Tasmania. In the passage from the 'feather' to the 'butterfly-wing' venation the angle between the midrib and the lateral veins becomes progressively more acute, and in the last two groups the yield of oil rises to a maximum of about 4·5 per cent., since there is more room for oil-glands between the lateral veins of the last two types than in the 'feather'-veined structure.

The primary type is persistent, some species being common to the western (Perth) and eastern (Sydney) regions, although no representative is known in Victoria (apart from the eastern coastal strip) or Tasmania. Even the most recent species are very old: more than half of the indigenous Tasmanian species are found on the mainland, and it is concluded that these must have been distinct species long before the formation of Bass Strait.

Besides the three main groups of *Eucalyptus* included in this supposed order of evolution, the evolutionary classification takes into account such exceptional species as *E. macarthuri* and *E. citriodora*, in which the chief constituents of the leaf-oil are geranyl acetate and citronellal



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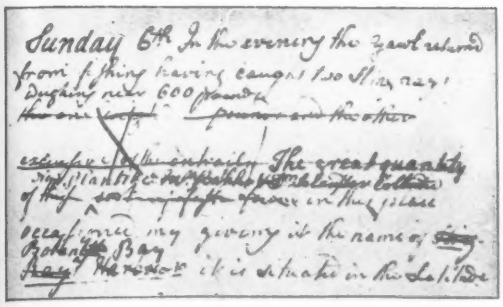

Sunday 6th. In the evening the yawl returned from fishing having caught two sting rays weighing near 600 pounds the one [illegible] pounds and the other [illegible] extreamly well tasted. The great quantity of [illegible] we caught there occasioned my giveing it the name of Stingray Harbour [illegible] it is situate in the Lat. of

FIGURE 1 – *'The name of* Botany Bay*': an entry in Captain Cook's Journal for 6th May,* 1770.
(With acknowledgments to the Commonwealth of Australia National Library.)

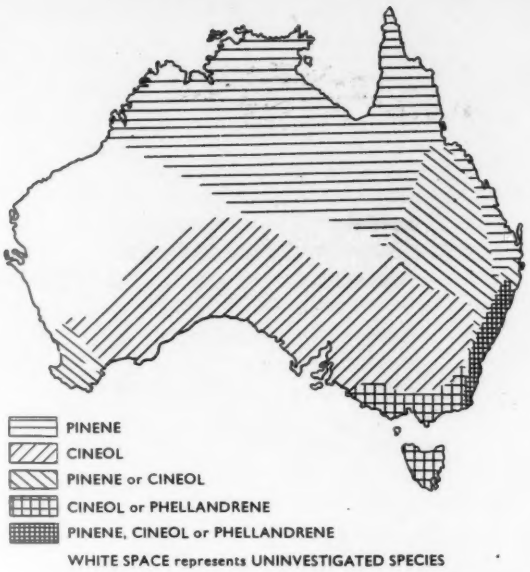

FIGURE 2 – *Phytochemical distribution of* Eucalyptus *in Australia. The map shows approximately the geographical limitation of* Eucalyptus *species according to the main chemical constituents in their oils.*
(R. T. Baker and H. G. Smith [2].)

FIGURE 3 – *Richard Thomas Baker* (1854–1941).

FIGURE 4 – *Henry George Smith* (1852–1924).

FIGURE 5 – Eucalyptus rostrata (*Murray Red Gum*). *Near Warburton, Victoria. This is the most widely distributed of all* Eucalyptus *species, as it grows on the banks of nearly every river in the interior of Australia.*

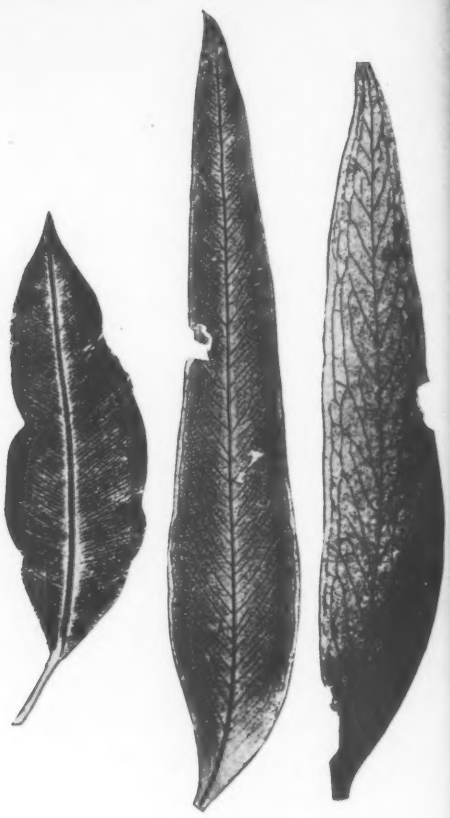

FIGURE 6 – *Types of* Eucalyptus *leaf-venation:* corymbosa (*Group* 1), E. smithii (*Group* 2), E. radi (*Group* 3). *Since the leaves are used as negatives, the glands appear as black dots. (Natural size.)*

FIGURE 7 – Darwinia fascicularis. *The leaf-oil of this Australian shrub is a rich source of geranyl acetate.*
(From a photograph by H. G. Smith.)

FIGURE 8 – dl-*Menthol from piperitone. This specim contains the finest crystals of the* dl-*form of natural menth on record, measuring up to about* 8 *cm. long.*
(From a photograph by J. Gerrard, St Andre

respectively. Baker and Smith regarded such isolated species as botanico-chemical outliers, or end members of sequences in which the passage forms have disappeared in the course of the evolution [13] [14].

These extensive researches were continental in scope, but Baker and Smith were men imbued with an extraordinary enthusiasm which no obstacles could daunt. They were apostles *par excellence* of the eucalypt. Towards the end of their labours they wrote: 'In the genus *Eucalyptus*, Australia has a commercial asset of so diversified and valuable a nature that it has no compeer in any other genus in the whole botanical world.'

MORE ABOUT AUSTRALIAN PLANT CHEMISTRY

Although the genus *Eucalyptus* overshadows the bush, there are many other Australian plants of great chemical interest [13]. Thus, besides eucalypts, myrtaceous plants include the so-called 'tea-trees,' belonging to *Melaleuca*, *Leptospermum*, and other genera, the popular name for which arose from Captain Cook's reputed use of the leaves of *L. scoparium* as a substitute for tea. These are shrubs or trees with sweet-scented leaves: the leaf-oil of *L. liversidgei*, for example, contains 60 per cent. of citral; *L. citratum* secretes citronellal as well as citral. An even richer citral oil, consisting of the almost pure substance, is found in *Backhousia citriodora*. *Darwinia fascicularis*, a low shrub growing on waste sandy land, yields a valuable leaf-oil which vies with that of *E. macarthuri* as a source of geranyl acetate.

Many of the handsome Australian acacias, or wattles—of which more than four hundred species exist—exude gums. Certain species growing in the arid western areas yield a good gum arabic, but this cannot be collected economically. *A. pycnantha*, *A. mollissima*, *A. decurrens*, and other species give excellent tanning extracts; these tan-barks, however, can be grown and gathered more economically in South African plantations.

Many Australian conifers belong to *Callitris*, the genus *Pinus* being unknown in the indigenous flora. According to Baker and Smith [3] [13], the genus *Callitris* also underwent evolutionary changes in traversing the continent from west to east. *C. glauca*, a typical 'western' species, affords the best source of an Australian 'pine-needle' oil, containing pinene and bornyl acetate; but *C. tasmanica*, an 'eastern' species, yields an oil containing 60 per cent. of geranyl acetate, being, surprisingly, a conifer which might be worked economically for geraniol. Of other Australian conifers, *Araucaria cunninghamii* (Moreton Bay Pine) is a magnificent timber tree; *Agathis robusta* (Queensland Kauri) gives an oleo-resin which is the most economic Australian source of a turpentine; and *Dacrydium franklini* (Huon Pine) furnishes a timber very resistant to insects, possibly because it contains methyl-eugenol. Unfortunately, before the advent of scientific forestry in Australia, there was a reckless 'cutting out' by skilled axe-men of these unique and magnificent species, without replanting.

To sum up: the myrtaceous plants—*Eucalyptus* and its congeners—are remarkable for their wealth of essential oils; the Australian wattles and 'pines' are predominantly sources of astringent material. It is impracticable here to enumerate alkaloids, dyes, glucosides, saponins, starches, fibrous celluloses, and other important organic products which various investigators have isolated from Australian plants. Finally, however, space must be found for a mention of the dainty pink-petalled *Boronias* (*Rutaceae*), with their intriguing scents and interesting oils; of the sassafras and sandalwood trees; and of the Grass Trees, or 'black boys' (*Xanthorrhoea* spp.), renowned for a yellowish resin from which picric acid may be made.

PHYTOCHEMICAL AND CHEMICAL PROBLEMS

A study of the Australian flora presents many attractive problems to the botanist and the organic chemist. The botanist, sometimes unable to go so far as the chemist in the differentiation of plant forms, will ask where a species ends and a variety begins. An interesting example is provided by *E. dives*, the type form of which shows a maximum proportion of more than 50 per cent. of piperitone in its oil. This is a species of high commercial value, and yet botanically the type form is inseparable from three varietal forms, in which the proportion of piperitone dwindles from about 20 per cent. to vanishing point, with an increase of phellandrene in one variety and the development of about 25 to 75 per cent. of cineole in the other two [6]. To what extent can chemistry serve in the classification of living forms?

The admirable name *Eucalyptus* was synthesized by L'Heritier in 1788 from the Greek *eu* (well) and *kalyptos* (covered), the allusion being to a protective lid or operculum which covers the inner part of the flower and falls off when the stamens reach maturity. For this and other

reasons, Baker and Smith considered that cross-fertilization occurs very rarely in the genus under natural conditions. Botanist and chemist alike would be interested to learn the effect of carefully controlled hybridization upon the chemical composition of eucalyptus oils. How would the chemical factors be inherited? Would it be possible to breed forms producing essential oils of particular value?

Some problems of a more purely chemical nature may be illustrated by referring to the ketone piperitone, which Smith showed in 1900 to be the peppermint-smelling ingredient of John White's Sydney Peppermint. This substance occurs in more than twenty *Eucalyptus* species, invariably in a laevo-rotatory or 'left-handed' (*l*) form. In 1921, J. L. Simonsen [12], working independently at Dehra Dun, India, discovered dextro-rotatory or 'right-handed' (*d*) piperitone in the oil of an Indian grass, *Andropogon jwarancusa*. These two piperitones, of the southern and northern hemispheres, are identical, except that their molecules are related as object and distinct mirror-image. A systematic study of the two forms of piperitone, begun at Sydney and continued at St Andrews [5] [9], has thrown much light upon chemical and stereochemical problems in the terpene group, besides leading to ideas of biochemical significance.

Firstly, by means of a network of delicate reactions, piperitone has been used as a source of each of the four menthols. Theoretically, each kind should exist in a 'right-' and a 'left-handed' form, together with a so-called *dl*-form composed of equal amounts of the two. As an outcome of this work, all of them have now been brought within reach of the chemist. One of the twelve forms (*l*-menthol) is identical with natural menthol from oil of peppermint (*Mentha piperita*).

Secondly, it has been found possible to proceed, by laboratory processes, from the 'left-handed' Australian piperitone to the 'right-handed' Indian piperitone, a stereochemical achievement of great interest.

Lastly, these chemical and stereochemical researches offer a clue to the biochemical relationships of the constituents of the Australian and Indian oils concerned. Baker and Smith held that the open-chain compound geraniol passed into *Eucalyptus* from the older genus *Angophora*, and probably runs through the whole genus, although often present only in small amounts. This view being accepted, geraniol is now presumed to function in *Eucalyptus* as the precursor of piperitol, piperitone, and phellandrene. A detailed theoretical scheme has been advanced, according to which the reactions take a slightly different turn in the Indian grasses, leading thereby from geraniol to piperitol and piperitone, with carene in place of phellandrene. The possibility of the two series of chemical reactions is clear, and some of the steps have been realized in the laboratory since the theory was first put forward; but in what way the plants discriminate between the 'left-handed' and 'right-handed' molecules remains obscure.

'The excessively delicate control of the molecular mechanism which is here implied appears to be a prerogative of the living organism. The organic chemist is powerless to effect such subtle differentiations by the artificial methods of the laboratory. At the present stage of our knowledge, the finer manifestations of organic synthesis appear to be inseparably bound up with vital processes' [9].

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The British Association

O. J. R. HOWARTH

The British Association for the Advancement of Science has acted as a model for many similar societies in different parts of the world. Dr Howarth, who has been Secretary of the Association for many years, and has an unrivalled knowledge of its history, here describes its origin, aims, development, and present-day activities. During the war, the Association has paid much attention to the coming problems of reconstruction and rehabilitation.

The objects of the British Association for the Advancement of Science, as set forth by its founders, are these:

> To give a stronger impulse and a more systematic direction to scientific inquiry; to promote the intercourse of those who cultivate science in different parts of the British Empire with one another and with foreign philosophers; to obtain more general attention for the objects of science, and the removal of any disadvantages of a public kind which impede its progress.

We are to glance now at the Association's history; and the form of these words has a historical interest in the use of the comparatives—a *stronger* impulse, a *more* systematic direction, *more* general attention. The year of the foundation was 1831. The period was one of adjustment in Europe—adjustment to peace after the Napoleonic wars, and to all the changes, for good or evil, connected with the industrial revolution. As for science, a century earlier there were a few intellectual people who were turning away from speculation in thought and toward the collection and interpretation of facts. As has been written elsewhere:

> these few started a mighty movement. And once the expanses of science began to be visualized, however dimly, science might appeal to any person with any capacity of thought at all: it dealt with things you could see or touch, from the stars in their courses to the wayside plant, from the expansion of steam in a kettle to the strange animal from a foreign land; and its applications were concerned with affairs of everyday life.

By the beginning of the nineteenth century the day of specialization was dawning: in the first half of that century twenty-four of the leading learned societies of London were established, about fifteen of them between 1830 and 1850. The founders of the British Association disclaimed any intention of trespassing upon the ground of such societies, and did not in fact do so, as will appear. But between them they provided the means to stronger impulse and more systematic inquiry.

In regard to relations with the State and the people, however, science felt itself neglected, and through the lips of some of its chief exponents said so in no uncertain terms. There were, and always have been, some, and some of the greatest, seekers after knowledge who were (and are) content with seeking for its own sake, not parsimonious of imparting their results to others, but at the same time little, if at all, concerned with the bearing of those results upon any wider interests. The position about 1830, however, was that a powerful element in the scientific community recognized the existence of other communities, whether willing to learn something of the meaning of science, or indifferent, or antipathetic to it, and conceived it to be the duty of science to foster the first of these and to join battle with the others. They were right: the British Association in its early years gained plenty of support, but also encountered both indifference and antipathy.

Scientists who at that period were dismayed at the state of science in Britain looked elsewhere for an example of better conditions and found it in Germany, a land then at a stage of enlightened progress in more than one direction. Here had been founded, in 1822, a society taking all science and the arts for its field, and designed to hold annual meetings in successive cities throughout the country. Its name was the Deutscher Naturforscher Versammlung. British scientists attended its early meetings and found in it a model. In Britain, scientific societies outside London were much less numerous than they afterwards became, but some already flourished locally. To one of them, the Yorkshire Philosophical Society, Sir David Brewster—editor, encyclopaedist, teacher, and physicist—addressed himself. Would the

society collaborate in organizing a meeting of friends of science in the city of York—centrally situated and easy of access from all parts of the country—with a view to the establishment of a permanent association? The society would, and did. And thus was brought to birth, on 26th September, 1831, the British Association for the Advancement of Science, with aims and practices so wisely defined by the group of leaders in science who attended the occasion that they survive in all essentials today, and have served as a model, even to the title, for similar bodies since established in other countries. Charles Dickens might pillory the professors of the 'Mudfog Association for the Advancement of Everything'; an astonishing dean of the Church of England might compose diatribes on 'The Dangers of Peripatetic Philosophy' and 'The Bible defended against the British Association'; but the movement prospered.

Brewster, as president of the Association in 1850, reviewed the preceding years, and mentioned many who had been or still were its active supporters: all were eminent in the science of their day, and the names of some will remain so always—Murchison, Dalton, Buckland, Whewell, Sedgwick, Airey, Herschel, Babbage, Lubbock, Lyell, Faraday, and the like. The Association was discharging its function of promoting contact with 'foreign philosphers,' and such names as Arago, Bessel, Struve, Liebig, and Agassiz appear among those of guests at its meetings. Pursuant to its undertaking not to trench upon the ground of other great societies, the Association never met in London until, by common consent, it did so for its centenary meeting in 1931. But in successive annual meetings it has visited all the biggest cities and towns in England, Wales, Scotland, and Ireland; it does so by invitation from the places themselves, and invitations have never been lacking. Only in years of war—1917 and 1918, and since 1939—have the annual meetings been intermitted. The founders had foreseen the possibility of movement beyond the confines of the home islands; but it was not until 1884 that the Association first held a meeting overseas—at Montreal. Since then Canada has been visited three times (1897, 1909, 1924), South Africa twice (1905, 1929), and Australia once (1914). 'Those who cultivate science in different parts of the British Empire' have thus been given the opportunities for contact promised by the Association. Moreover, a new precedent was established in 1937–38, when the Indian Science Congress Association invited to its jubilee meeting a representative scientific delegation organized by the British Association; and many of us hope that that precedent may be followed more generally in the future. The Association, under its charter, is free to wander where it is bidden; and delegations to kindred bodies, both within the Empire and elsewhere, should be within the bounds of possibility in years to come.

From almost its first years, the Association devoted to the promotion of scientific research and inquiry any funds which remained in hand after meeting working expenses. These funds have never been large, even in recent years when generous gifts were made to the Association by Sir James Caird of Dundee (1912), specifically for research, and by Sir Charles Parsons (1921) and Sir Alfred Yarrow (1926) for the general purposes of the Association. The inquiries thus modestly assisted have been supplemented by an immense amount of voluntary labour, and have covered a very wide range. Two features call for remark: one, the frequency of inquiries initiated by the Association and subsequently carried on by Government or other agencies more appropriate and better able to finance them; the other the method of calling for reports 'on the state of science' in any given department, according with the 'more systematic direction' of inquiry aimed at by the founders.

The compilation of the British Association Catalogue of Stars, seismological and tidal investigations, terrestrial magnetism, the computation of mathematical tables, British rainfall, marine biology, are all among subjects on which the Association focused inquiries during the first ten years of its existence. With some of them (notably seismology and mathematical tables) the Association has continued to concern itself to this day. The Association's work on electrical standards, initiated in 1861, resulted in the formulation of the system adopted internationally in 1908. Among other inquiries there may be mentioned anthropometric investigations in the British Isles (from 1875), which provided the basis for other such studies of later date, and in particular proved their value when during the war of 1914–18 it became necessary to take stock of the country's man-power. Investigations connected with early man have always been prominent. The engineering section has set on foot many practical inquiries; the education section has issued many factual reports on the position of science as an educational subject. In the realm of economics, it has been authoritatively

FIGURE 1 – *Sir David Brewster* (1781-1868). *Physicist, editor, encyclopaedist, and Vice-chancellor of Edinburgh University. A founder of the British Association.*

FIGURE 2 – *Sir Richard Gregory, Bt., F.R.S. The present President of the Association.*

FIGURE 3 – *Charles Darwin's study at Down House, Downe, Kent. In this room* The Origin of Species *and many other books were written.*

stated that the Association's work in connection with the patent laws of 1883 and 1885 'represents one of the most powerful public acts in its history.' One other incident connected with the Section of Economics should find place here because it must have few if any parallels in the history of scientific societies. The Association met in Belfast in 1874 at the time of a protracted strike in the linen industry. The Section of Economics was to receive a report and papers in which the subject of strikes was included incidentally. Representatives of masters and men in the industry were invited to attend, and discussion naturally centred on their own particular dispute. Economists present were able to apply such healing balm that it was possible for Tyndall, president of the Association, to announce next day that the dispute had been settled then and there.

Consideration of space denies the extension of this list, jejune as it may appear when joined with the remembrance that inquiries carried on under the auspices of the Association during the past century run to many hundreds in number. But before leaving this side of the Association's activities we must recall the episode of Kew Observatory. This institution existed a century before the Association was founded, and for a period it belonged to the Crown; but in 1841 it was on the point of being abandoned when the Association took it over and maintained it from 1843 to 1872. During this time it fulfilled many important functions, the chief of which was perhaps that of a testing-house for magnetic and meteorological instruments, watches, and various other appliances which needed the control of standards. The Observatory passed into the hands of the Royal Society in 1872, and so continued until early in the present century; and through the action, first of the Association and then of the Society, there may be traced in succession the origins of the great National Physical Laboratory of the present day.

The presidency of the Association, accounted one of the highest of scientific honours, is an annual office. Only in war-time has this rule been suspended: thus the late Sir Arthur Evans held office in 1917–18, and the present president, Sir Richard Gregory, was appointed in 1940. In the early years of the Association a layman of noble rank and high standing in the locality of the meeting was sometimes inducted into the chair—that practice accorded with (what is called) the spirit of the time. Moreover, the active interest of the Royal Family was shown by the acceptance of the presidency by the Prince

FIGURE 4 – *The pistol, powder-flask, bullets, ramrod and key, and a "blackjack," carried by Darwin on the voyage of* The Beagle, *and now in the custody of the British Association.*

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Consort in 1859 and by the Duke of Windsor (as Prince of Wales) in 1926; and it may be added here that King Edward VII in 1904 conferred upon the Association the royal patronage which has been continued by his successors, and that the Royal Charter of incorporation was granted in 1928.

Apart from these occupants of the chair, the list of presidents includes, it may be said, every most eminent name in British science during the lifetime of the Association—save one, and that among the most eminent of all: Charles Darwin. It was his poor health alone that forbade his acceptance of the office. It is the more fortunate that his name has been brought into peculiarly intimate relationship with the Association. The British Association provided one of the principal platforms for the discussion of his views as set forth in *The Origin of Species*. He himself could take no part in this: but his champions, such as Hooker and Huxley, did so powerfully, and so did his opponents, such as Owen and Bishop Wilberforce. Notably, the meeting of 1860 brought the protagonists together on the platform: of their performances thereon it need only be said that the scientific representatives presented their case with knowledge and dignity; their opponents with neither. Long afterwards, in 1927, Sir Arthur Keith, as president of the Association, reviewed in his address the position of 'Darwinism,' and pleaded for the preservation of Darwin's home at the quiet village of Downe, in Kent, as a national memorial, knowing that, given the necessary funds, the place could be acquired for that purpose. Next day it fell to the writer of this notice—and it was an unforgettable moment—to open a telegram from Mr (now Sir) Buckston Browne, F.R.C.S., a fervent admirer of Darwin, offering to acquire the property for the purpose which the president had in mind. The thing was done: the donor acquired Down House forthwith, restored it, and gave it in trust to the Association, with an endowment towards its upkeep, in 1929. Many relics of Darwin's own were forthcoming from many generous sources and are preserved in some of the rooms. In particular, the study in which he wrote all his most famous works was furnished almost exactly as he had it. These rooms and the pleasant grounds of the house were open to the public until war broke out in 1939; they had been viewed by thousands during the preceding ten years, and will be so again when peace returns. This is the inscription which guides visitors to the gates: 'Here Darwin thought and worked for forty years, and died, 1882.'

During the war of 1914–18 and for a little while afterwards there was some tendency on the part of the public towards dismay at the powers of science when put to evil uses. In the ensuing period the powers of science for good became increasingly manifest; but they were not, and still are not, sufficiently widely understood. The British Association must needs still strive for 'more general attention for the objects of science.' Important measures to this end were undertaken shortly before the present war. In 1936 the British Science Guild was incorporated into the Association. The object of the Guild (at that time under the presidency of the present Lord Melchett) was 'to promote the application of scientific method and results to social problems and public affairs.' The same object is implicit in those of the Association, and the union of the two bodies strengthened the Association in the discharge of its public functions.

Already in previous years those responsible for framing the Association's programmes had been increasingly insistent upon the inclusion of subjects of broad general interest at the annual meetings, but 'a more systematic direction' was needed for these. No one of the sections among which the work of the Association is distributed bore this specific charge upon it. A Division for the Social and International Relations of Science was therefore established in 1938, with the object of focusing attention on applications of science to the public benefit and of stressing the international character of science; for among all human activities science has approached most nearly to the ideals of international collaboration. The new Division differed administratively in some respects from the Sections, notably in being empowered to hold meetings independently of the general annual meetings.

This power has been used during the present war. It was clearly impossible under war conditions to hold the great annual meetings of peace-time. But the Division has been able to arrange conferences, simple in organization but effective in result, taking for their field problems of post-war rehabilitation and settlement, towards which science has essential contributions to make. The first of these conferences was held under the title of 'Science and World Order,' and reviewed a whole series of such problems. It attracted wide public attention and disclosed a number of subjects which demand further treatment.

The evolution of British cartography

M. N. MacLEOD

There are few who do not respond to the mute appeal of a map—even when it is only penny plain and not twopence coloured—and the larger the scale of the map the greater its power of attraction becomes. Major-General MacLeod, who was for some time Director-General of the Ordnance Survey of Great Britain, here relates the story of the development of British cartography from the beginning of the nineteenth century up to 1939.

A map is a conventional picture of a part of the earth's surface on a sheet of paper or the like. Maps which show large areas, such as whole countries, whole continents, or even the whole world on a single sheet, are called 'atlas' maps. Those which portray a country on several sheets fitting together to form a 'series' are generally known as 'topographical' maps, though there is no hard-and-fast dividing line between the two.

The earliest known maps are all of the first type. The now familiar maps used by walkers, motorists, engineers, estate agents, etc., are comparatively new things in the world's history, dating only from about the end of the eighteenth century. The ancients do not seem to have had anything at all similar, though they may have had route maps, and 'cadastral' maps showing only property and field boundaries. The first nation to publish a topographical map of its country in the modern style was the French. The surveys for this map were started in 1745. The British followed towards the end of the century with a map on the scale of one inch to one mile, the first sheet of which was published in 1801. This map was produced in order to assist the Army in the defence of the country—the need for such assistance having been much felt in Scotland during the suppression of the '45 rebellion—and its production was placed under the direction of the Master-General of the Ordnance, who at that time performed most of the functions of the present Minister of Supply.

Progress on the map was slow at first. There was no recognized technique for surveying on such a scale; and the soldiers who were charged with the work had virtually to invent their technique as they went along. By the time that Napoleon had been finally liquidated at Waterloo, and defence had ceased to be a matter of pressing concern, only about half of England had been done. A few years later, however, another urgent need, of a different kind, suddenly arose. The British Parliament decided to try to settle the Irish question by buying out some of the big landlords and reselling their land at reduced rates to smallholders, and a map was wanted to help in carrying out this policy. The English one-inch map had shown how useful a map could be for such purposes, but for this particular purpose every field had to be shown, and the one-inch scale was too small. Eventually it was decided to try to map Ireland on the scale of six inches to one mile, notwithstanding that this would require thirty-six times as many sheets as a one-inch map. Seeing that the mapping of a part of England about the size of Ireland on the one-inch scale had just taken twenty years, this was a very bold decision. It proved, however, to be a very wise one. The 'Ordnance' survey, still plodding along with the one-inch map of England, was entrusted with the work and rose nobly to the occasion. Its Director-General, Colby, by applying mass-production methods, accelerated progress so much that within another twenty years the great new task was finished. And so useful did the new map prove, not only for land purchase, but also for a host of other purposes, that there was an immediate call for a similar map of Great Britain. Work on this was started at once, but soon people began to point out that if a scale of six inches to one mile was so useful in agricultural Ireland, a much larger one would be appropriate for industrial England. Unfortunately it proved almost impossible to secure any agreement as to what this larger scale should be, and nearly fifteen years of controversy followed before the Government took another bold decision and decided to map Great Britain (with the exception of some of the sparsely populated mountainous areas) on the scale of 1/2,500, or a little over twenty-five inches to one mile.

SALISBURY

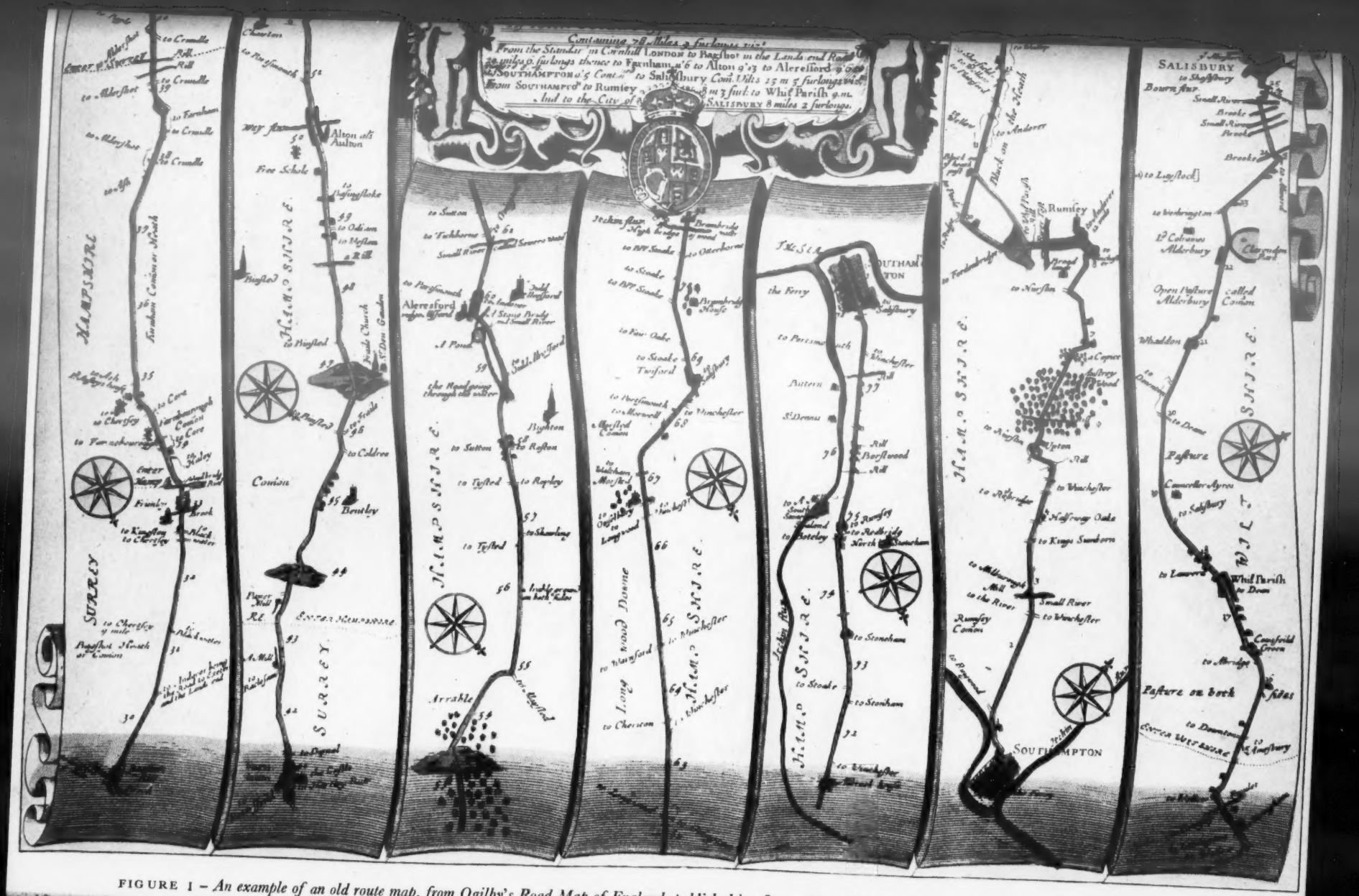


FIGURE 1 – *An example of an old route map, from Ogilby's Road Map of England, published in* 1655. *The original is in the possession of Mr Alexander Duckham.*

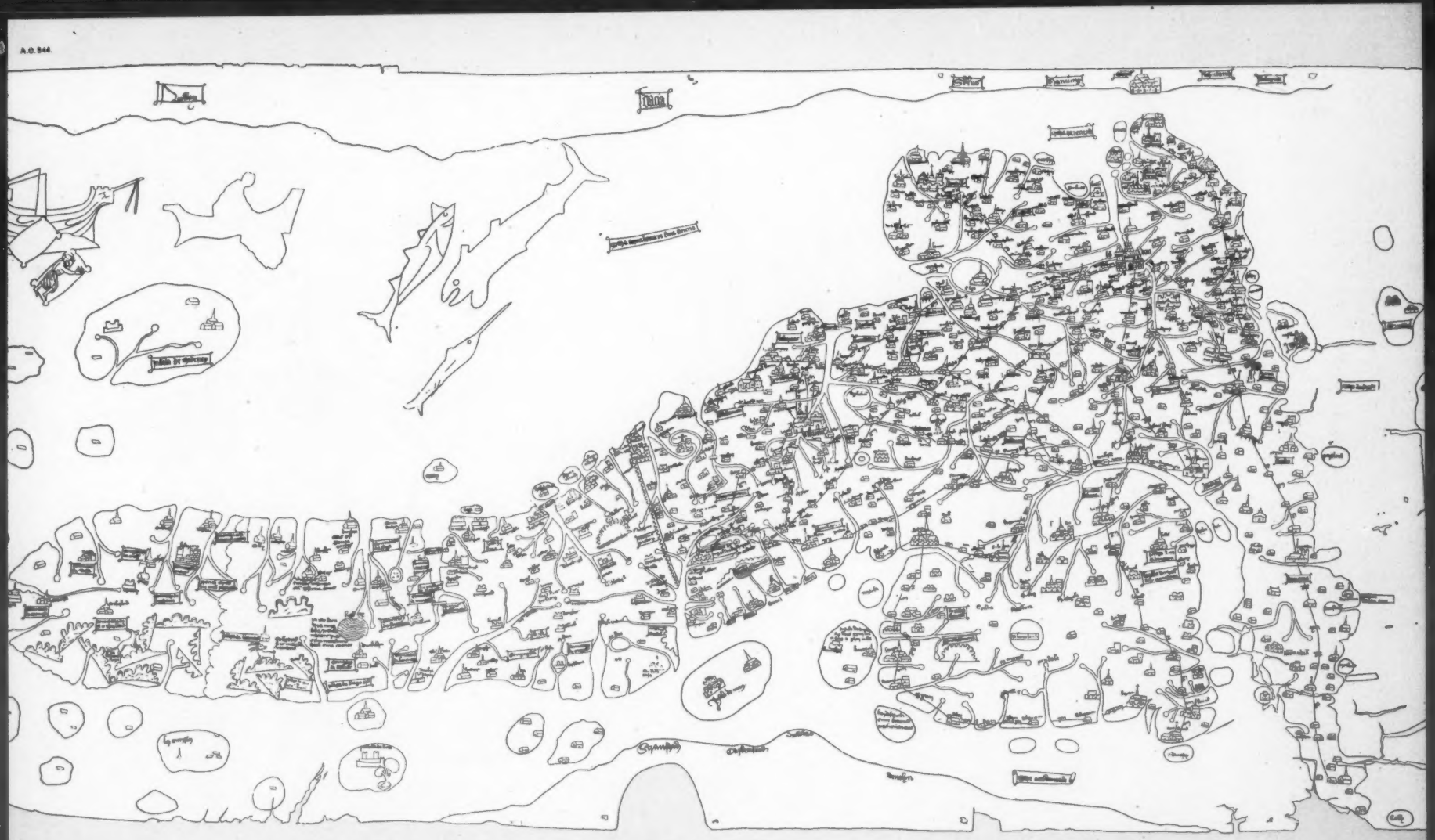
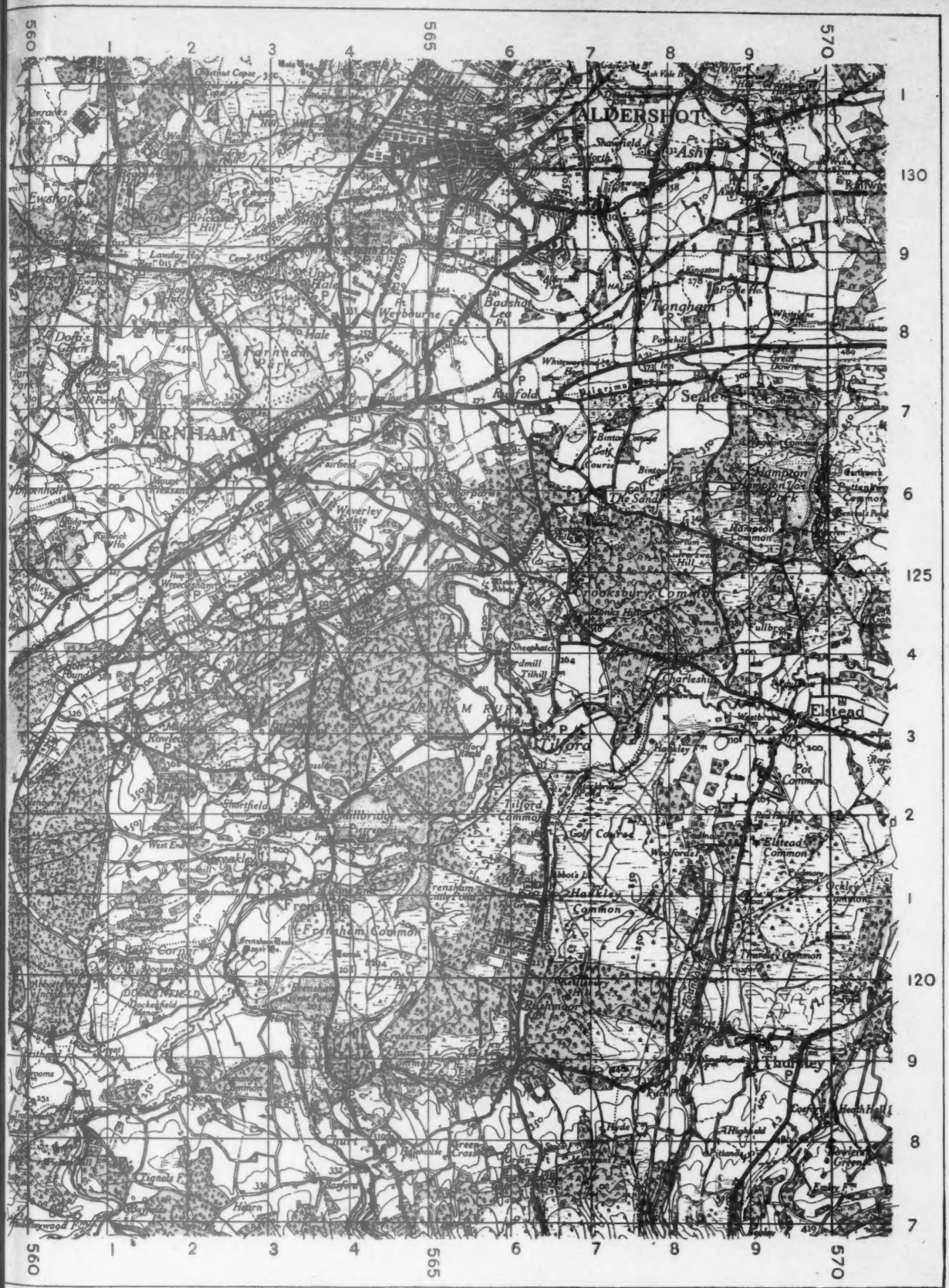


FIGURE 2 – *A portion of a fourteenth century map of England. The original is in the Bodleian Library.*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Rushmoor
Hankley Common
Thursley Common
Elstead Common
Tilford Common
Frensham Common
Crooksbury Common
Pot Common
Ockley Common
Golf Course
Golf Links
Golf Club
Aerodrome
Aerodrome (Disused)
Aerodrome (Civil)
Aerodrome (Military)
Airfield
Camp
Barracks
Rifle Range
Firing Range
Church
Chapel
Wesleyan Chapel
Primitive Methodist Chapel
Baptist Chapel
Congregational Chapel
Mission Room
Cemetery
Burial Ground
Public House
Inn
Post Office
Telephone
Telegraph
Police Station
Police House
Coastguard Station
Lighthouse
Lighthouse (Disused)
Beacon
Signal Station
Signals
Windmill
Windmill (Disused)
Windpump
Windpump (Disused)
Water Tower
Water Tower (Disused)
Reservoir
Pumping Station
Sewage Works
Sewage Farm
Gasworks
Quarry
Sand Pit
Chalk Pit
Clay Pit
Gravel Pit
Marl Pit
Mine
Mine (Disused)
Shaft
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Tunnel
Tunnel (Disused)
Cutting
Embankment
Viaduct
Bridge
Bridge (Disused)
Ford
Footbridge
Suspension Bridge
Pier
Jetty
Slipway
Boathouse
Boatyard
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Wharf
Quay
Landing Stage
Ferry
Ferry (Disused)
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Electricity Transmission Line (Disused)
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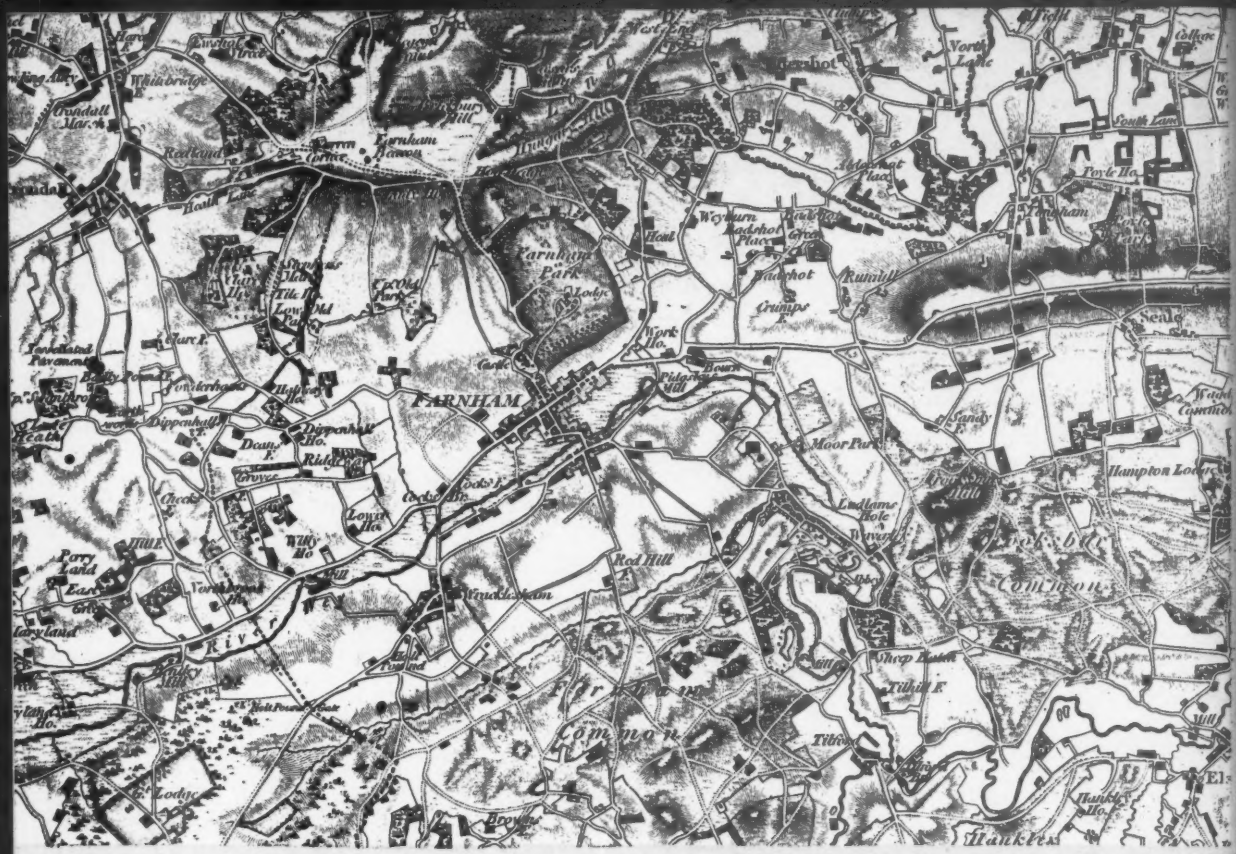
FARNHAM
Farnham Park
Moor Park
Hampton Lodge
Red Hill
Sandy Hill
Crooksbury Hill
Tilford
Runfold
Hankley
Scale
Rumill
Crumps
Wyburn
Hunt
Work Ho.
Pitch Hill
Dippenhall
Tongham
Runfold Pavement
Perry Land
Lodge
Grove
Lower Ho.
Wily Ho.
Hill
Tilth E.
Sheep Leaze
Ludlams Hole
Down
Common
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Hurt F.
Deans
Ridge
Cooks F.
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Tenantry Farm
Tilth
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Brow
Hankley Ho.
Hankley Common
Hankley Farm
Moor Park
Sandy F.
Hill
Rowland
Wrecclesham
Farnham Park
Lodge
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Tenantry Farm
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Sheep Leaze
Ludlams Hole
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Common
Heath
Hurt F.
Deans
Ridge
Cooks

This was a prodigious task, requiring more than 50,000 sheets, in addition to over 10,000 sheets of the six-inch map which was to be published as well. No other country has yet attempted anything like this. None has mapped all its territories even on the six-inch scale and not many have managed even half this size. The British 1/2,500 map was started in 1855 and took about forty years to complete. It now forms the basis of a whole range of maps on scales down to 1/1,000,000—the scale of the *Carte Internationale du Monde*.

Only fifty years have elapsed since the great twenty-five-inch map of Great Britain was finished, and half a century is not a long time in the life of a nation. While there is no doubt that the country gets very good value from the map, it is probable that, as it continues to gain experience, it will be able to get still more. New uses for good and reliable maps are constantly being found; but it is becoming clear that the fullest value of any particular map can be secured only when it forms part of a well-arranged cartographic system, in which there are several types of map, on scales related to one another in convenient ratios; so that any project or operation can be studied as a whole on maps of small scale, and its subdivisions examined separately on maps of larger scale showing the ground in greater detail. British maps were not, of course, designed for use in this manner, but changes which were about to be made when this war broke out—and which will doubtless be made as soon as peace is restored—will improve them in this respect. Among these changes is the addition of a 'grid,' a cartographic device invented during the last war in order to provide a means of indicating the positions of points and places not named on the map. A map grid is, in effect, a graphic representation of the rectangular co-ordinates used by mathematicians for defining the positions of points on a plane surface, and appears on each map as a network of squares, any one of which can be indicated by a number, called a 'map reference.' In addition to other uses, a map grid greatly facilitates the comparison of one map with others of the same area on different scales.

The addition of a grid was not the only contemplated improvement in British maps, though it was perhaps the most interesting. There was also an intention to rearrange the sheets of the 1/2,500 and six-inch maps in a more convenient form, and to take the opportunity of giving them a thorough overhaul. The reasons for embarking upon this formidable task are rather too technical to be given here, but the fact that such admirable maps should need overhauling only fifty years after their completion is a useful reminder that there is no finality in cartography. Man and nature are continually changing the face of the country, and a first-class map must record these changes without undue delay. In Great Britain the need for periodical revision was apparent long before the original survey was finished, and authority was given in 1882 for the publication of revised plans at intervals of twenty years. Revision did not actually start until 1896, and was then done county by county in rotation. The 20-year period was maintained, and sufficed reasonably well, until the outbreak of war in 1914, when the work of revision had inevitably to be greatly restricted. When peace was restored, the development of the motor-car led to a campaign of road and house construction which caused such rapid and extensive changes in the countryside that revision of the maps lagged sadly behind. Before long, the obsolescence of British maps, upon which many people had come to depend, began to cause the greatest inconvenience, and when Parliament passed such Acts as the Housing and Slum Clearance Act of 1930, and the Finance Act of 1931 which taxed land values, matters reached something like a crisis, since Acts of this kind cannot easily be administered without good and up-to-date maps. After the Town and Country Planning Act of 1933, the Government decided to take action, and, on the advice of a Committee presided over by Viscount Davidson, provisionally approved a number of measures which would, in due time, have restored British maps to something more than their old level of excellence. The outbreak of war in 1939 again interfered with the execution of these plans, but the episode has been useful in showing, on the one hand, that well-executed and reliable maps are now much more than a mere convenience, and are in fact almost indispensable tools—in peace no less than in war—for the orderly and efficient conduct of affairs; and, on the other, that mapping, even with the aid of the most recent technical devices such as air photography, is a slow process which cannot be suddenly and indefinitely accelerated by Acts of Parliament or grants of money, however liberal. It is to be hoped that the stress of greater events will not cause the lesson to be overlooked or forgotten.

New precision in atomic constants

H. R. ROBINSON

The absolute masses of individual atoms, and the magnitude in electrostatic units of the electronic charge, are now known with an accuracy of 1 part in 4,000 or 5,000. How this precision of measurement has been achieved is here explained by Professor Robinson, who sketches the successive stages of progress from the pioneer work of Sir J. J. Thomson to contemporary data provided by the latest types of mass spectrograph.

Here is an extract from an edition, published about 1850, of the Reverend Jeremiah Joyce's *Scientific Dialogues:*

> *Emma:* I remember, papa, that you told us something strange about the divisibility of matter, which you said might be continued without end.
>
> *Father:* I did, some time back, mention this curious and interesting subject, and this is a very fit time for me to explain it.
>
> *Charles:* Can matter indeed be infinitely divided; for I suppose that this is what is meant by a division without end?
>
> *Father:* Difficult as this may at first appear, yet I think it very capable of proof. Can you conceive of a particle of matter so small as not to have an upper and under surface?

Charles immediately sees the point of this leading question, and deduces, at some length, that matter *must* be infinitely divisible. Father approves: 'Your conclusion is just.'

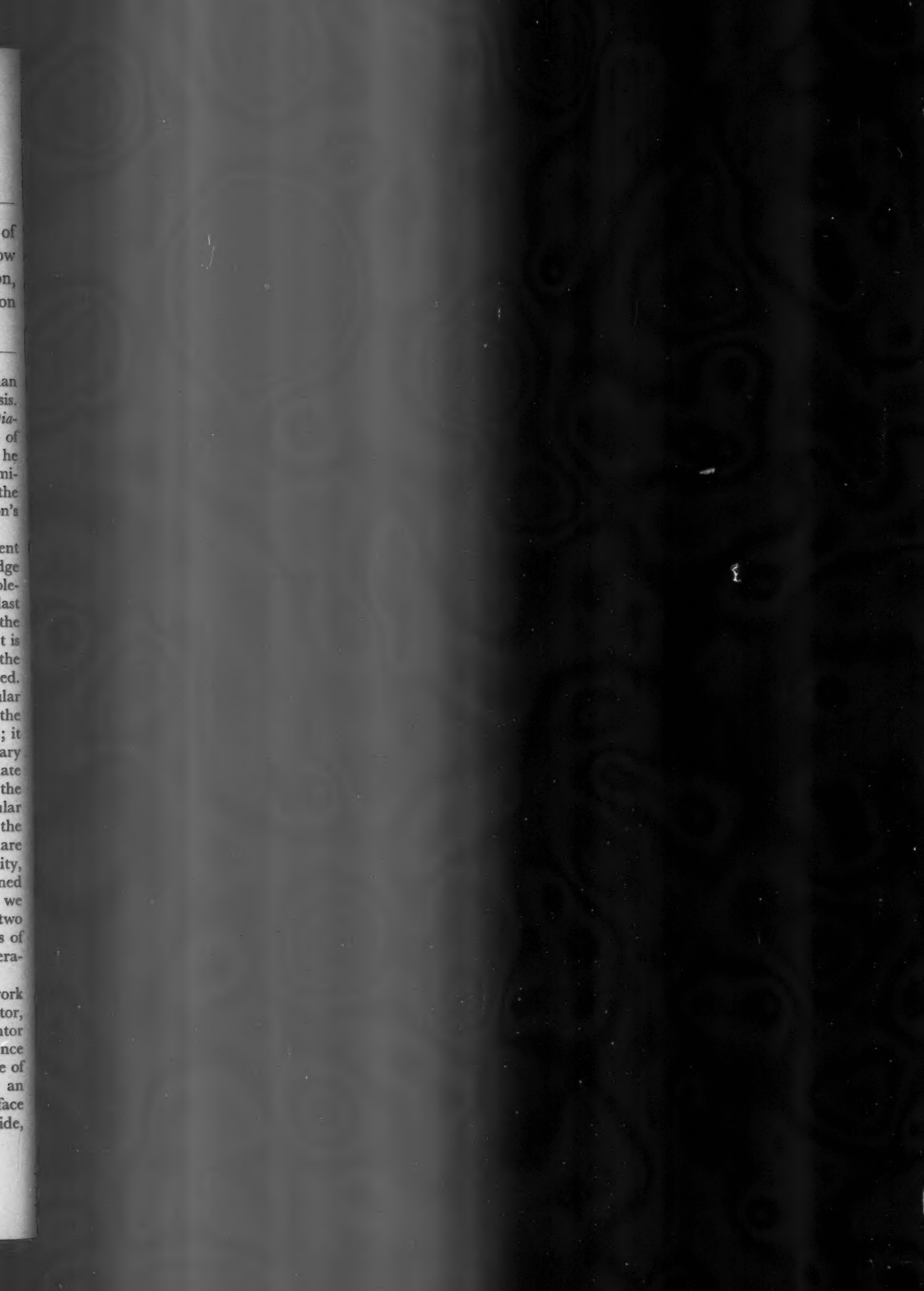
In a later edition, of 1875, revised by 'men eminent in science' and 'completed to the present state of knowledge,' all the above, including Papa's approval of Charles' conclusion, is reprinted without change, but with the addition of a very cautious rider, saying that most philosophers now adopt the atomic view of matter, 'although it is perhaps a question which is incapable of satisfactory solution.'

This quotation has not been introduced with the unworthy object of poking easy fun at an outdated text-book of elementary science. Joyce's *Dialogues* were, in and for their time, like the celebrated *Conversations* of Mrs. Marcet, an excellent introduction to popular science. The extract is intended simply to serve as a reminder of the great change that has occurred, in the last seventy years, in our attitude to atomic theory. In spite of the contributions made by Dalton, Gay-Lussac, and Avogadro in the first few years of the nineteenth century, it was not until nearly the end of that century that Dalton's atomic theory was fully recognized as anything more than a convenient and powerful working hypothesis. Today, in a hypothetical new edition of the *Dialogues*, Papa would certainly take the 'reality' of atoms and molecules as axiomatic, and (if he could keep them from prattling about Fermi-Dirac statistics) he would be likely to give the children at least a simplified account of Aston's work on isotopic masses.

Atomic theory owes much of its present authority to the detailed and accurate knowledge of the properties of individual atoms and molecules which has been accumulated during the last few decades, and more particularly since the development of electrical theories of matter. It is the purpose of this article to indicate some of the ways in which this knowledge has been acquired.

Oddly enough at first sight, the first molecular magnitude to be accurately known was the average value of the molecular speed in a gas; it is over ninety years since that extraordinary genius, J. P. Joule, deduced an approximate expression for the pressure of a gas in terms of the gas density and the square of the mean molecular velocity. Soon afterwards Clausius derived the more exact expression in which the mean square velocity replaces the square of the mean velocity, and since 1859, when Clerk Maxwell obtained the law of distribution of molecular speeds, we have known the precise ratio between these two means, and even the fraction of the molecules of a given gas whose speeds lie, at a given temperature, between any two assigned limits.

I have no knowledge of any experimental work on molecular speeds earlier than that of Cantor, carried out in Strasbourg in 1897. What Cantor did in effect was to measure the difference between the thrusts on two equal surfaces, one of glass and the other of copper, suspended in an atmosphere of chlorine. As the copper surface captures some of the chlorine to form a chloride,



the number of molecules rebounding from it is less than from the glass surface, and the pressure is correspondingly lower. The measured difference, together with a knowledge of the mass of chlorine collected per second by the copper surface (obtained by weighing the plate at intervals of a few minutes), leads quite simply to a deduction of the mean square molecular velocity. All that can be said of Cantor's results is that they are of the order of magnitude predicted by the kinetic theory. The method is obviously not precise, and the experiment is unsatisfactory in a not uncommon way, viz. there are so many palpable sources of error that it would be almost as easy to dismiss the result if it did not agree with theory as it is to accept it when it does. The work deserves mention, however, as an ingenious early attempt to confirm the predictions of the kinetic theory of gases. It appears to be very little known, for I have mentioned it to a number of well-read physicists without finding one who had heard of it before. Direct experiments on molecular speeds and their distribution came much later, with the application of Dunoyer's method of working with well-defined molecular beams.

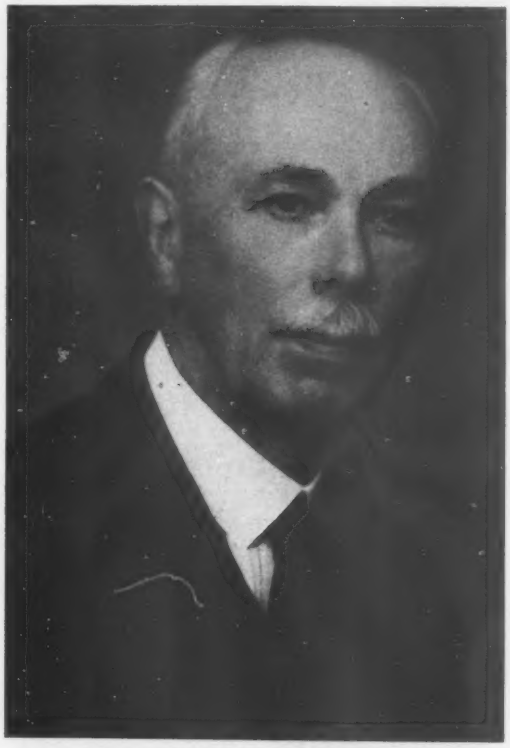
Sir J. J. Thomson.

Kinetic theory, combined with data from other branches of physics, also gave us our earliest estimates of the mass and size of the individual molecule—though none but the most naïve of physicists could ever have thought that he had a very clear idea of the exact meaning of the 'size' of a molecule. On the whole, however, the late Victorian scientists had considerable reason to be satisfied with the state of this particular branch of knowledge. The original method of Loschmidt was known to give upper limits for the mass and size, and other methods based on simple theories of dielectric action were known to give lower limits. The ratio of the upper to the lower limit varied somewhat from gas to gas, but 80 is a fairly representative value; further, a slightly more recondite argument, making use of the constant b in van der Waals' equation, very neatly split the difference between the two extreme values, so that molecular masses might be said to be known certainly in order of magnitude, and possibly to within 50 or 100 per cent. There was, however, nothing to show whether the subject of the calculations was a definite molecular mass, or merely an average value, corresponding to a group of many particles whose individual masses might vary, continuously or discontinuously, over a fairly wide range. A wide spread of the individual masses would have been revealed by diffusion experiments, but in the last century there was no experimental technique capable of detecting a spread of a few per cent.

We now know the masses of individual atoms to a degree of accuracy that would have seemed totally unattainable fifty years ago, and we know the nature of the spread in the masses, which is in fact discontinuous. The first steps in this amazing advance were made in the Cavendish Laboratory, by J. J. Thomson and the remarkable group of physicists he attracted to Cambridge. In 1897 Thomson, independently of and almost simultaneously with Wiechert in Berlin and Kaufmann in Königsberg, measured the specific charge of the negative electrons in a discharge tube; he deduced correctly that the electrons were far less massive than even the lightest atoms, and showed that they were constituents of all ordinary matter. Soon afterwards J. S. Townsend, by a brilliantly conceived and executed series of experiments, proved that the electronic charge, e, was identical in magnitude with the charge carried by a univalent electrolytic ion. Next, Townsend, Thomson, and H. A. Wilson made independent determinations of the electronic

charge, using methods developed in the same laboratory by C. T. R. Wilson in his work on cloudy condensation.

From that time onwards—that is, from about the beginning of this century—there has been no room for reasonable doubt of the atomicity of electricity, and (if we ignore, for a moment, isotopy) the accuracy of our knowledge of individual atomic masses has been limited solely by uncertainty about the precise value of e. The derivation of the masses is very simple and straightforward, for since Faraday's pioneer work (1833) we have always had the means of knowing accurately the ratio of mass to charge of electrolytically transported atoms in bulk; it is simply given by the atomic weight, on the ordinary scale, of the elements concerned, divided by the valency and by Faraday's constant of electrolysis. According to Professor Raymond T. Birge, who knows more about these matters than almost everyone else combined, this bulk ratio of mass to charge is now known to within about 1 part in 10,000. We get the mass of a single atom by multiplying the bulk ratio by the charge carried by a single ion, which is $n \times e$ for n-valent elements.



F. W. Aston, F.R.S.

The Cambridge pioneer measurements of e were subject to relatively large errors, and it is to two United States physicists, R. A. Millikan and A. H. Compton, that we primarily owe our greatly improved knowledge of this important atomic constant. Millikan substituted fine oil-drops for the water-clouds used by Thomson and Wilson; thus, instead of being restricted to hasty observations upon the upper surface of a rapidly disappearing cloud, he was able to make prolonged measurements of the behaviour, under accurately controlled conditions, of an almost perfectly stable drop. He made a detailed study of the possible sources of error, and the result, which he published in 1917, was generally supposed to be correct to within 1 part in 1,000. Later oil-drop experiments, notably the very recent ones made by Laby and Hopper in Melbourne (1941), have confirmed the remarkable accuracy of Millikan's work. It has, however, become clear that Millikan's final value for e was in error by about 7 parts in 1,000, this error being mainly due, not to inaccuracies in Millikan's own experiments, but to the adoption of an incorrect value of the viscosity of air in the calculation of the result.

Millikan's method was essentially an elaboration and improvement (the two terms are not necessarily synonymous in experimental science) of the older Cambridge experiments, whereas Compton's broke entirely new ground. Compton was the first to realize the possibility of using, under suitable conditions, an ordinary ruled diffraction grating for the spectroscopy of X-rays, and thus of measuring the wave-lengths absolutely. Such measurements, taken in conjunction with measurements of the angles of reflexion of the same X-rays from crystal faces, lead quite simply to an evaluation of e. Accurate crystal measurements were already available when Compton and Doan first succeeded, in 1925, in obtaining X-ray grating spectra. The first results, for which high accuracy was not claimed, were in approximate agreement with Millikan's e. Later work, in which the accuracy has been developed to a degree almost comparable with that achieved in crystal spectroscopy by Siegbahn and his schools in Lund and Uppsala, has led to a value of e which is generally accepted as correct to within 1 part in 4,000 or 5,000. It is $4{\cdot}802_1 \times 10^{-10}$ absolute electrostatic units; Millikan's value was $4{\cdot}770 \times 10^{-10}$, and recent work on the viscosity of air tends to show that the difference between the two may very largely be explained

away. The theory of the X-ray method has been subjected to very careful and competent scrutiny, with satisfactory results, and the value of e has been confirmed, in an elegant but less direct manner, by the X-ray refraction experiments of J. A. Bearden. There are therefore exceptionally strong grounds for confidence in the precision of our knowledge of the electronic charge, and hence of atomic masses.

The story is, however, incomplete without a reference to another field of research which has been intensively cultivated in the Cavendish Laboratory. Early in this century J. J. Thomson developed his well-known 'parabola' method of investigating the positive rays discovered in 1886 by Goldstein. In this method, charged atoms are deflected by parallel electric and magnetic fields, and fall ultimately upon a photographic plate. For a given charge, atoms of a given mass produce a parabolic trace upon the plate; if the mass of the atoms varied continuously over a certain range, the trace would be correspondingly broadened. In fact, allowing for inevitable broadening attributable to the geometry of the apparatus, there is no evidence of any such variation. In 1912, however, Thomson made the remarkable discovery that neon gave two distinct parabolas, lying closely side by side—showing, as one possibility, that neon atoms could be divided into two groups, both indubitably neon, corresponding to two definite and distinctive masses. This view was eventually substantiated, and some years later a third group was found, showing that there are three kinds of neon atoms.

Thomson's photograph of the parabolas of neon was the first clear indication of the existence of non-radioactive isotopes. It was the starting-point of a long chain of investigations which has shown that in most elements the atoms are not all identical in mass; they can, however, be resolved into definite groups—generally not very many groups[1]—of identical particles. It is in this sense that chemical atomic weights, and the early estimates of the masses of individual molecules, relate only to average values, viz. the means of the various isotopic masses, weighted according to their relative abundance.

Our knowledge of these matters is derived mainly from the work of F. W. Aston in Cambridge. Following a trail indicated by Thomson's parabolas, Aston began at once to try to separate a sample of pure neon gas into identifiably different components by diffusion. Later he turned to the more powerful method of separation of positive rays by electric and magnetic fields. In his first mass spectrograph (a celebrated instrument, now in the Science Museum at South Kensington) he created a research tool of vastly greater power than the parabola apparatus. It was ready for use in 1919, and with it Aston at once confirmed Thomson's result with neon, and showed that many other elements were mixtures of isotopes.

Since 1919 the isotopes of the chemical elements have been very thoroughly investigated; initially the bulk of the work was shouldered by Aston himself, with the original mass spectrograph and later with more refined models using the same principle. More recently other types, with very high performance, have been built and used by other workers—notably by Dempster (an early pioneer of positive ray analysis), Bainbridge, Jordan, and Nier in the United States and Mattauch in Vienna. In the two or three years preceding the present war, numerous other workers appeared in the field, and we now have an immense body of detailed and accurate knowledge of the relative masses and abundance of isotopes. In the measurement of relative masses an accuracy of 1 part in 100,000 is commonplace, and one part in a million is claimed for Jordan's latest instrument, announced in 1940. The knowledge so acquired has been of great value in very varied fields. It is as a mere by-product of it, and of the precision with which e has been measured, that we now know the absolute masses of individual atoms with an accuracy of about 1 part in 4,000 or 5,000, i.e. not much less accurately than we know so old-established a constant as the mechanical equivalent of heat. The mass of the lightest atom known is $1{\cdot}6734 \times 10^{-24}$ gram.

This sketch has dealt in the main with one aspect only of the properties of individual atoms and molecules—that is with no more than a very small fraction of the knowledge that has been acquired during the past forty-five years. I hope that it may be read in the light of a remark made by Kelvin in 1883: 'I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it.' If we accept this dictum (and it is a meiosis to say that there have been, and are, authorities whose dicta are in general less trustworthy than Kelvin's), enough has been said to show at least that we do now 'know something about' atoms.

[1] Tin, for instance, which is exceptionally complex, has ten isotopes, ranging from 112 to 124 atomic mass units, with a weighted mean of 118·70.

Advances in the scientific knowledge of rubber

E. H. FARMER

Rubber, with its enormous molecular weight (about 350,000), is a difficult substance to investigate chemically. The molecule is so long and twisted that only small, mobile, reagent molecules will act upon it quickly and completely. Recently, however, very much progress has been made in the chemistry of rubber, which Dr Farmer shows to possess a latent chemical versatility of great interest. This is likely to increase its utility to industry.

The rapid increase during recent years in the manufacture of synthetic materials, some of which possess a measure of rubber-like properties, has given an impetus to research into the fundamental characteristics and future economic possibilities of natural rubber. The discovery in 1839 that rubber can be vulcanized, by simply heating it with sulphur, and thereby transformed from a tacky, deformable, and somewhat elastic material into a non-tacky one having enormously improved elasticity, tensile strength, and stability in air, proved to be the foundation of the modern rubber industry. Rubber, as most people know it today, is vulcanized rubber, which means that most of the rubber articles of everyday life are essentially composed not of the rubber hydrocarbon but of a chemical modification of it. Hence the question arises: Is vulcanization the only useful chemical transformation in the rubber repertory, or can other chemical processes convert it into a range of materials each of which excels sufficiently in some group of physical properties to render it the most suitable material for a particular industrial enterprise? Some progress towards answering this question has been made along empirical lines during the past fifteen or twenty years, but a complete answer can be obtained only when the fundamental properties of the rubber hydrocarbon have been systematically investigated. Some recent discoveries which reveal unexpected capacities and complexities in the properties and chemical behaviour of rubber are reviewed in the following account.

THE SIGNIFICANCE OF THE MOLECULAR FORM OF THE RUBBER MOLECULE

When rubber had been shown by Pickles to be built up of recurrent isoprene units, $—CH_2·C(CH_3) = CH·CH_2—$, linked end to end, it remained for Staudinger to assess the number of such units in the average molecule of the hydrocarbon. Staudinger's estimate of *ca.* 2,200 has now been revised after careful study by Gee [13], and stands at the value of *ca.* 5,000 (molecular weight, 350,000). The immense length of the molecule which Gee's value discloses provides certain embarrassments for the chemist, who has to bring the molecules to reaction in bulk. Viewed from the standpoint of classical organic theory, each rubber molecule contains in its chain an average of 20,000 carbon atoms (apart from those in attached methyl groups); it has an innate capacity for free rotation of its parts to occur about each of its 15,000 C–C links; and it displays a fixed *cis* configuration about its 5,000 double bonds. Some idea of what this means in magnitude and molecular form may be gauged from figure 1 [18], which represents a saturated paraffin molecule having about one-twentieth the chain-length of the rubber molecule, and not complicated by configurational restrictions arising from the presence of recurrent *cis* linkings. Such sinuous and unwieldy molecules must inevitably become badly entangled with one another, so that they are no longer able to move freely as a whole. Consequently successful reaction between the thousands of potentially reactive units comprising each chain and any reagent molecules that are placed in juxtaposition will be greatly facilitated by small size and ready mobility in the latter, since this will enable them to pass between the chains and approach the nearly immobilized rubber units.

COMBINATION OF RUBBER WITH SMALL AND LARGE MOLECULES

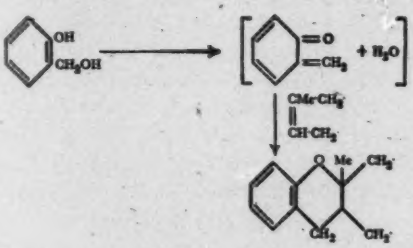
No difficulty is experienced in practice in bringing about *complete* and rapid reaction between all the units of the rubber chains and small,

mobile, reagent molecules such as those of hydrogen chloride. On the other hand, where the reagent molecule is very large or is attached to a bulky catalyst surface, the problem of physical approach becomes acute. This is well seen both in the case of catalytic hydrogenation and in that of combination with phenol-formaldehyde resins. In these processes the practical difficulty of approach can be overcome in quite different ways.

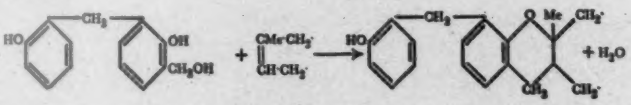
The hydrogenation of rubber by treating it with hydrogen in the presence of a catalyst has engaged the attention of many chemists, because it has appeared reasonable to expect that if rubber were deprived of all, or nearly all, of its unsaturation it would then be resistant to atmospheric oxidation but would retain in large measure those properties dependent on its great molecular size. Hydrogenation proved in practice to be very difficult; and all the early workers believed that the difficulty in achieving substantial reaction was due to poisoning of the catalyst by impurities in the rubber, and hence was to be overcome by very drastic (and usually very deleterious) purification of the rubber. According to modern views, it is necessary for each of the ethylenic centres of the rubber to become adsorbed, at some point in the process, on the catalyst surface, in order to take therefrom the necessary pair of hydrogen atoms. Hence the physical problem is a little like that confronting an enormously long and three-dimensionally coiled worm, which, without straightening, must bring every segment of its body, one or more at a time, in contact with certain spots distributed over the ground. Only by prolonged and violent contortions may its object be achieved. Staudinger partly overcame the difficulty of hydrogenation by using a high temperature, a fairly high hydrogen pressure, enormous amounts of catalyst, and a very long reaction time. Hydrogenation does occur under these conditions, but serious cracking and cyclization changes readily occur too. It is now found possible, by adjusting the temperature of reaction within fairly narrow limits, and by using a supported nickel catalyst, to cut down to moderate values the amount of catalyst and the time of reaction required for complete hydrogenation; and also to reduce the working pressure to about 15–20 atms. [11]. The most critical feature is the temperature, for although a fairly high temperature (170–195° C) is necessary to promote the rather violent thermal agitation of the rubber chains requisite to secure effective contact of all the ethylenic units with the catalyst surface in a reasonable time, yet too high a temperature causes not merely the severe cracking and cyclization referred to above, but probably also the recombination of the thermal degradation products. This last occurrence is almost certain to lead to branching in the reconstituted chains. In practice, the rubber can be hydrogenated (with or without a measure of cracking as desired) to any required point up to complete saturation. The uncracked hydrogenated products are rubber-like solids, resistant to oxidation, and showing elasticity over a rather lower temperature range than rubber. Severely cracked hydrogenation products, on the other hand, are semi-solids (*see* figure 2).

RUBBER IN RESINS

A hitherto undescribed way of bringing about chemical combination of rubber with large molecules is to build up the latter on the former. This has been accomplished in the case of phenol-formaldehyde resins by uniting very simple phenol-formaldehyde condensation products ('Novolaks') with some of the ethylenic units in rubber, and afterwards cross-linking the resinous parts of the product. For this purpose the 'Novolaks' can be formed in presence of rubber by the aid of an acid catalyst, but only those aromatic nuclei which contain a $\cdot CH_2OH$ group in the ortho-position to a phenolic $\cdot OH$ group can be directly joined to rubber [4]. The unions occur quite easily at moderate temperatures and entail the formation of a chromane ring at each junction, as is shown for saligenin and ortho-ortho-linked di-saligenin in equations (*a*) and (*b*). Subsequently



(*a*)



(*b*)

the dried rubber-'Novolak' resin can be ground with hexamethylenetetramine and employed as the resinous component of moulding powders and

for the impregnation of textiles and paper. Hardening occurs when the mixture is heated and subsequently cooled. In technological practice somewhat oxidized rubber (commercial 'Rubbone') is used in place of raw rubber in order to ensure the compatibility of all the resin-forming ingredients. In this material, points of junction with the 'Novolaks' are believed to occur with fair frequency along the lengths of the rubber chains. A conventional representation of the kind of complex formed is given in figure 3.

The resin has the unique property among the resins of 'Bakelite' type of possessing some residual thermoplasticity after normal thermosetting has occurred. This very useful property enables flat sheets of resin to be bent, or pressed into curved forms, after being warmed to 120–130° C (*see* figure 4). The basic addition-reaction occurring between saligenin, di-saligenin, etc., and rubber appears to be applicable to a wide variety of other olefinic substances, not merely to rubber.

THE IMPORTANCE OF RADICALS

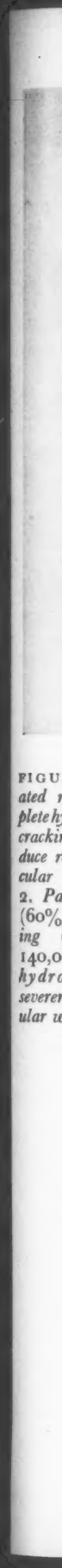
Rubber is a polyolefinic substance and hence has the ability to add suitable reagents at the double bonds of its units. This is now known to be only one of the ways in which it can react. It will be borne in mind that owing to its hydrocarbon character and relatively low solubility, rubber is almost invariably brought to reaction either dissolved in hydrocarbon solvents or in the solid form. In both these conditions the almost non-polar ethylenic units are surrounded by a non-ionizing medium. In such circumstances ionic reactivity is not favoured, and in its place a strong tendency towards another type of reactivity, *radical* reactivity, makes itself apparent, in which the participants are not electrically charged ions but neutral radicals and molecules. The main basis of this behaviour is the capacity of the rubber molecule to permit certain of its hydrogen atoms to be displaced or detached by the reagents it meets. What happens afterwards depends on circumstances, but the net result is that rubber is highly reactive, although the mechanism of reaction is often intricate.

A good deal of information about the radical reactivity of rubber has been derived by experiments on oxidation [10], [12], a process which proceeds sufficiently readily to cause the gradual deterioration (perishing) of rubber when the latter is exposed to air in a bright light without chemical protection. Naturally, the way in which oxygen acts has been studied very carefully in order to allow the most effective steps to be taken to prevent this deterioration. There are far too many units in any rubber chain to allow the chemist to tell what happens to any representative one of them during reaction, and the task is not rendered easier by the fact that those units which succeed in reacting may be dotted here and there along the chains and may not reach the same stage of reaction simultaneously. Therefore it is usually preferable in determining the course of reaction between rubber and any particular reagent to make the early experiments with one-, two-, or six-unit rubbers, which are fortunately available, and then to compare the results with those obtained using rubber itself. Such experiments show that the individual rubber units absorb oxygen to form hydroperoxide groups which become attached to the chain at one or other of the three black C atoms in $\cdot CH_2 \cdot C(CH_3) : CH \cdot CH_2$. This means, selecting one (the most likely) of the three C atoms as representative, that a unit which reacts with a molecule of oxygen passes by some mechanism through the stages (*a*), (*b*) and (*c*), asterisks being used in the formulae to denote the radical centres:

$$\cdot CH \cdot C(CH_3) : CH \cdot CH_2 \cdot \xrightarrow{(a)} \cdot CH \cdot C(CH_3) : CH \cdot CH_2 \cdot \xrightarrow{(b)}$$
$$\quad | \qquad\qquad\qquad\qquad\quad *$$
$$\quad H$$

$$\cdot CH \cdot C(CH_3) : CH \cdot CH_2 \cdot \xrightarrow{(c)} \cdot CH \cdot C(CH_3) : CH \cdot CH_2 \cdot$$
$$\quad | \qquad\qquad\qquad\qquad\quad |$$
$$\quad O \cdot O^* \qquad\qquad\qquad\quad O \cdot OH$$

The questions then arise: How is the hydrogen atom lost or detached in stage (*a*)? Does an oxygen molecule help in its removal, or is its separation aided by light (or heat) alone? The questions have been difficult to answer conclusively. On the one hand, several workers have observed that the rate of oxidation of rubber and of other somewhat similar olefinic substances is independent of the oxygen concentration, and hence it might appear that the oxygen is not directly concerned in the first stage of the process. On the other hand, the severing of the C–H bond requires the expenditure of a considerable amount of energy which must be supplied from some source. Since, however, the oxidation of rubber proceeds most rapidly in sunlight or ultra-violet



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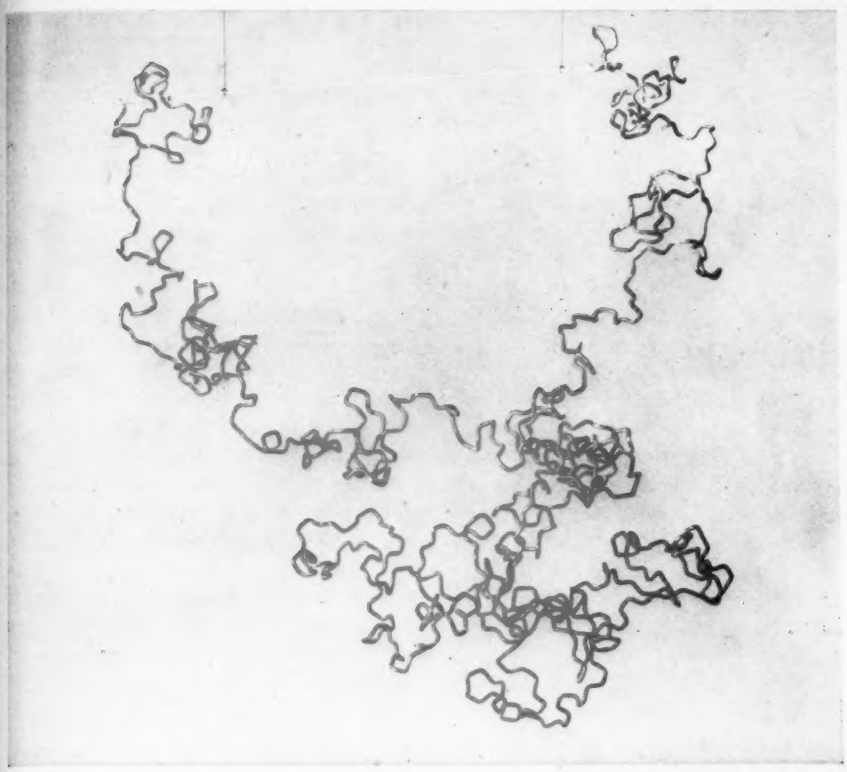


FIGURE 1 – *Treloar's large-scale model of a paraffin molecule of molecular weight* 14,000, *based on the statistical theory of Kuhn. The effect of random rotation about the* C–C *bonds is reproduced, the direction in space at each bend in the wire having been determined by the throw of a die. The distance between the ends proved to be about* 9 *in., a value very near to the theoretical value for the most probable length of this model molecule. The length when fully extended would be* 14 *ft., so that the extensibility of a* 1,000 *link paraffin molecule is about* 19 *times.*

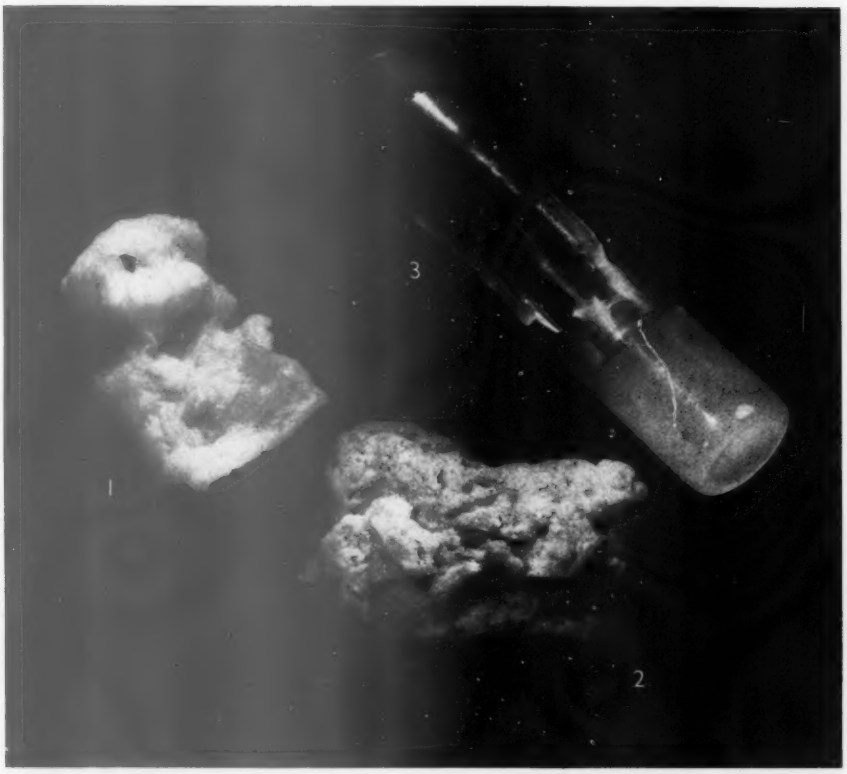


FIGURE 2 – *Hydrogenated rubber:* 1. *Complete hydrogenation. Slight cracking allowed to reduce reaction time (molecular weight* 150,000). 2. *Partial hydrogenation* (60%) *with slight cracking (molecular weight* 140,000). 3. *Complete hydrogenation with severer cracking (molecular weight* 49,000).

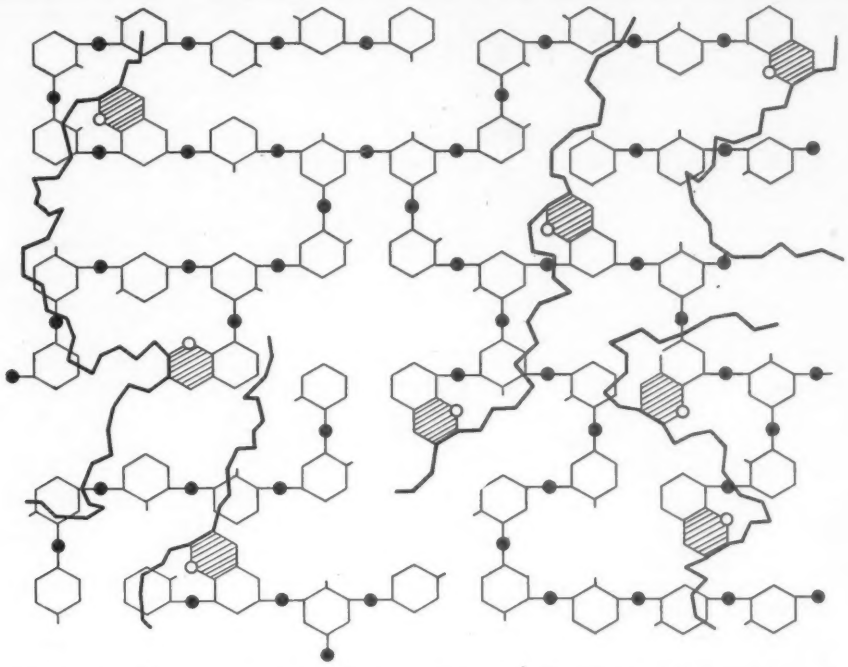


FIGURE 3 – *Conventional planar diagram of the three-dimensional molecular network in rubbone-phenol-formaldehyde resin. The black irregular lines represent rubber chains which effect junction with the phenol-formaldehyde network through the shaded oxygenated (chromane) rings. The unshaded hexagons represent phenol nuclei; their tails,* ·OH *groups; and the black dots* $\cdot CH_2$ *groups.*

FIGURE 4 – *Laminated boards of rubbone-phenol-formaldehyde resin reshaped after the original thermosetting had occurred.*

light (i.e. under conditions which are in general known to favour the formation of neutral radicals from a variety of organic substances), it is reasonable to assume provisionally that the light-promoted oxidation at least involves the formation of radicals, and to pass on to view the consequences. It should, however, be noted in passing that rubber and similar polyolefinic substances undergo slow oxidation in the dark, i.e. thermally distinct from essentially photo-oxidation, and this phenomenon has been little investigated.

The correspondence of expectation with observed behaviour under the radical hypothesis is perhaps best seen in the case of methyl linolenate (derived from linseed oil) and the esters of various fish-oil acids which closely resemble methyl linolenate in structure [7]. These polyolefinic substances all undergo oxidation in air and light, like rubber, but have the double merit for the present purpose that the peroxides formed are much more stable than those of rubber and so do not confuse the issue by too early decomposition. Moreover, the arrangement of unsaturation in their carbon chains lends itself to the perception of structural changes more readily than does that of rubber. Methyl linolenate has the formula:

$$CH_3{\cdot}\underbrace{CH_2{\cdot}CH{:}CH{\cdot}CH_2{\cdot}CH{:}CH{\cdot}CH_2{\cdot}CH{:}CH{\cdot}CH_2}{\cdot}(CH_2)_6{\cdot}CO_2CH_3$$

in which the pairs of ethylenic carbon atoms are separated by only one methylene group instead of two as in rubber. Only the bracketed 10-carbon system need be considered. In this system the two CH_2 groups between the pairs of double bonds would be expected on general organic principles (and have, indeed, been found in practice) to be more readily susceptible to attack by reagents than the two outside CH_2 groups. If through irradiation of the ester in air the left-hand one of these CH_2 groups were temporarily to lose a hydrogen *atom*, with or without the assistance of a molecule of oxygen, then the resulting 10-carbon radical system (*A*) would contain two 3-carbon groups **1** and **2**, each one of which (alternatively) would be expected to fluctuate or resonate between the radical forms $\cdot CH{:}CH{\cdot}\overset{*}{C}H\cdot$ and $\cdot\overset{*}{C}H{\cdot}CH{:}CH\cdot$, until ultimately the missing hydrogen atom became replaced by another atom or group. Consequently the two radical forms (*B*) and (*C*) would be likely to appear immediately, in addition to the original form (*A*), and these would ultimately give, by collision with oxygen molecules followed by abstraction of hydrogen atoms from the surroundings, two different peroxido-molecules. Both these peroxido-molecules, however, unlike that similarly derived from (*A*), would display diene conjugation, i.e. they would have two of their double bonds alternating with single bonds—a condition which is easily recognized and measured by spectrographic means. Five additional peroxido-forms displaying diene conjugation, together with one showing triene conjugation, could arise if the right-hand CH_2 group, or the left- *and* right-hand CH_2 groups, together or in succession, lost hydrogen atoms. Therefore any serious degree of oxidation of the ester which involved radical formation could not fail to produce a considerable degree of diene conjugation and possibly a little triene conjugation. In practice it is found that when pure methyl linolenate absorbs one molecular proportion of oxygen in sunlight at room temperature (i.e. enough oxygen to attack every other CH_2 group) about one-third of the molecules show diene conjugation and 5 per cent. triene conjugation, and up to nearly the end of this absorption *all* the oxygen is present in the form of peroxide groups. Very similar results are obtained with the similarly constituted, but longer, unsaturated systems in the fish-oil esters; but with none of the esters can light, in the absence of oxygen, bring about any significant degree of conjugation. It seems necessary to conclude, therefore, that in ordinary oxidation-practice oxygen *is* directly concerned in the first stage of reaction, i.e. the formation of the organic radicals.

In the case of natural rubber or its low-molecular analogues the method of peroxide formation is similar to that in the esters. Here, however, the presence of *two* CH_2 groups between the ethylenic pairs of carbon atoms precludes the

$$\overset{\overset{1}{\frown}}{\cdot CH_2{\cdot}CH{:}CH{\cdot}CH{:}CH{\cdot}CH{:}CH}{\cdot}CH_2{\cdot}CH{:}CH{\cdot}CH_2\cdot \qquad (A)$$

$$\cdot CH_2{\cdot}\overset{*}{C}H{\cdot}CH{:}CH{\cdot}CH{:}CH{\cdot}CH_2{\cdot}CH{:}CH{\cdot}CH_2\cdot \qquad (B)\ \text{(by resonance of 1)},$$

$$\cdot CH_2{\cdot}CH{:}CH{\cdot}CH{:}CH{\cdot}\overset{*}{C}H{\cdot}CH_2{\cdot}CH{:}CH{\cdot}CH_2\cdot \qquad (C)\ \text{(by resonance of 2)},$$

possibility of any significant degree of conjugation occurring by the radical mechanism; and in addition the peroxide groups decompose swiftly after their formation, so tending to destroy unsaturation and to defeat observation. Consequently it is to be expected that no serious degree of conjugation will be observed in practice, an expectation which is realized experimentally.

Another well-known way of forming radicals from carbon compounds is that of heating them to high temperatures. With methyl linolenate and the fish-oil esters such formation occurs, in entire absence of oxygen [6], well below the cracking point, if the appearance of conjugation [15] is taken as a criterion. Here, however, the final degree of conjugation is small compared with that obtained by oxidation (< 5 per cent.), owing to the onset of polymerization among the conjugated forms. In the case of the rubbers, on the other hand, although radicals are doubtless formed, no conjugation appears on heating, and none would be expected in view of their constitution.

The formation of hydroperoxide groups as described above is only the first part of the oxidation process in rubber; for these groups readily decompose and act as veritable oxidizing agents for the material in which they occur [9]. The groups break down under the influence of light and of heat in a complex manner, the net effect being to oxidize the double bonds within reach, first oxygenating them (usually forming epoxy groups) and then severing them. In the early stages of oxidation a dozen or more oxygen molecules have to be absorbed to cause one complete break in the chain, but the process goes on steadily, with progressive shortening of the chains, even although only a few of the double bonds attacked are severed. Normally each ·OOH group retains half its oxygen as an ·OH group in the original position, and applies half to the oxidation of the chains. The process is exactly that which rubber technologists have used for many years to soften rubber. The rubber is kneaded in air between the rollers of a mill and so absorbs oxygen; its long chains are broken down by the oxidation to about one-third (on average) of their original length, so that the product is more tractable and more soluble. Of course, this convenient softening is effected by sacrificing in some degree those properties of toughness, resistance to mechanical shock, etc., which depend on the great length of the rubber chains. If the milling process is carried much further with the aid of a chemical oxidation catalyst, the rubber loses its solidity and a very useful material, 'Rubbone' [14], [16], [17], in which the rubber chains have been broken down to about one-ninetieth or less of their original length, is produced. The oxidation process, however, does not tend in all circumstances to reduction of the molecular size, because if the peroxide groups are decomposed at high temperature (e.g. on hot rollers), some of the chains or fragments become joined by oxygen links—mostly of ether type—to form heterogeneous chains.

DIVERSE COURSES IN CHLORINATION

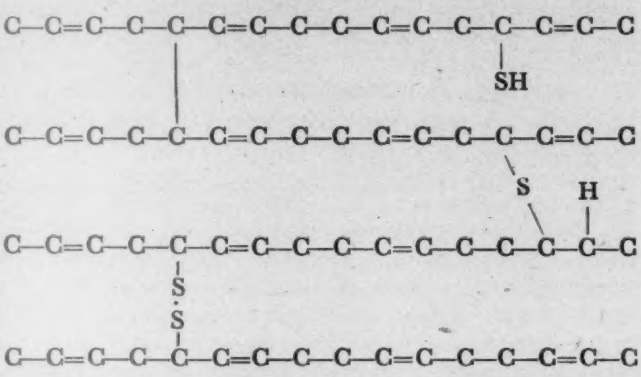
Highly chlorinated rubbers prepared by the action of chlorine on rubber have been extensively used in the manufacture of acid-resisting paints, but the less heavily chlorinated rubbers are unstable. When chlorine reacts with rubber between $-50°$ and $+80°$ C, the first molecule of reagent replaces a hydrogen atom of the rubber by chlorine, and the second largely does likewise. Only at the later stages of reaction does the chlorine begin to add at the double bonds. Indeed, it is necessary to resort to a stratagem to prepare the homogeneous additive dichloride $[\cdot CH_2\cdot C(CH_3)Cl\cdot CHCl\cdot CH_2\cdot]_n$, which is a relatively stable compound. The hydrogen atoms replaced by chlorine are found to be mainly those of methylene groups adjacent to the double bonds, but to a large extent cyclization accompanies halogenation. Thus two distinct types of substituted units are formed, $\cdot CHCl\cdot C(CH_3):CH\cdot CH_2\cdot$ and $\cdot CH\cdot C(CH_3):CH\cdot CH_2\cdot CH_2\cdot C(CH_3)\cdot CHCl\cdot CH_2\cdot$, both being very unstable and losing their chlorine completely by interaction with alcoholic silver nitrate [2]. The simplest and most coherent explanation of these facts is that both compounds are formed by direct displacement of hydrogen by the chlorine, which possibly involves radical reactivity. The additive reaction, too, is unlikely to be of ionic character.

RADICALS AND VULCANIZATION

The linking of rubber molecules to form immense insoluble complexes which occurs when rubber is heated with sulphur has long been thought to be an additive process in which sulphur acts simultaneously as an addendum for the double bonds and as a linking agent. The role of accelerators, however, in speeding up and often improving the vulcanization has not been understood. The simplest form of vulcanization is now recognized [5] to be that which is slowly effected by sunlight or ultra-violet light, and this can be

interpreted as resulting from the slow expulsion of hydrogen atoms (very slow compared with the rate of detachment of hydrogen atoms in oxidation processes) from the rubber chains by the light [1]. Any rubber molecule RH which loses one of its hydrogen atoms in this way forms an active radical R* which by collision with a neighbouring molecule can unite with the latter and expel a hydrogen atom ($R^* + RH \rightarrow R{\cdot}R + H^*$). The process can be continued either by the double molecule becoming a radical through loss of a hydrogen atom and then uniting with a third rubber molecule ($R{\cdot}R \rightarrow R{\cdot}R'^* + H^*$; $R{\cdot}R'^* + RH \rightarrow R{\cdot}R'{\cdot}R + H^*$), or by a third molecule of rubber becoming a radical and uniting with the double molecule ($RH \rightarrow R^* + H^*$; $R{\cdot}R + R^* \rightarrow R{\cdot}R'{\cdot}R + H^*$), and so on. The active hydrogen atoms expelled in the process can supplement the stock of radicals, which are formed so slowly by the action of light, and thereby help to keep the process going. A much more rapid reaction of the same kind can be brought about by adding to rubber an organic substance which itself breaks down into radicals. Such a substance is dibenzoyl peroxide [8], which gradually breaks down on being warmed, and doubtless some at least of the well-known accelerators owe their effectiveness to the same property. Usually, however, these organic materials in the process of contributing radicals add part of their substance to the rubber, thus chemically modifying it as well as cross-linking it. Sulphur achieves cross-linking at an early stage of its action on rubber [3]. Probably it owes its efficiency to its ability to detach hydrogen atoms from the rubber, so forming rubber radicals and thiol radicals ($RH + S \rightarrow R^* + HS^*$), the former of which would mostly become linked with neighbouring molecules by C–C bonds. The latter would either combine with, or extract hydrogen atoms from, adjacent rubber molecules, thereby forming (respectively) rubber radicals or hydrogen sulphide. In this way cross-linked structures such as that shown below would be formed.

The principle of vulcanization serves also in the linking of rubber with other molecules. Thus when dissolved rubber is warmed with maleic anhydride in presence of a source of radicals (dibenzoyl peroxide), the radicals from the latter apparently detach hydrogen atoms from the rubber and so enable it to start combining with maleic anhydride. In this way technically interesting materials containing up to 1 molecule of the anhydride per rubber unit can be obtained. In other chemical processes, too, including the orderly thermal cracking of rubber, the formation of radicals from the rubber appears to play an important part. Sometimes, however, the ready formation of rubber radicals during reaction is an embarrassment, promoting cross-linking where the chemist merely desires to add reagents to the double bonds. In this case, premature vulcanization sets in, and instead of the normal, relatively soluble products expected highly insoluble ones are obtained.



In the past the remarkable physical properties of vulcanized rubber have made rubber one of the world's coveted basic materials: it seems likely that in the future the chemical versatility of rubber will afford means of extending its usefulness and thereby reinforcing its position in industry.

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The influence of hormones on man's social evolution

S. ZUCKERMAN

Certain glands produce chemical substances, called hormones, which have a profound and vital effect on the functioning of the body. The processes of reproduction, for example, are completely dependent on changes produced by the sex-hormones. This article discusses, in general terms, the thesis that human evolution was related to changes in Man's sex-hormone physiology.

The story of human evolution is one of broad outline and little detail. A study of fossils shows that men possessing a skeleton identical with our own coexisted with somewhat different human types, as represented by Neanderthal man, in an early part of the present geological epoch, about half a million years ago. Beyond the fact that these other types died out, little else is known with certainty. How far back modern man reaches, and what his links were with extinct human types and with extinct and existing types of ape or monkey, remain unsettled questions. By what mutational changes we diverged from our parent types, and what selective processes ensured the perpetuation of these changes, are problems veiled in complete ignorance. In the circumstances, it is hardly surprising that theories of human evolution are still essentially broad and simple generalizations.

We do not yet know enough to do more than emphasize certain major factors that appear to have helped in the emergence of our species, and in the assumption of our present dominant position in relation to other forms of life on the globe. Most of these factors are unique characteristics in our biological make-up and modes of behaviour; unique in the sense that without them it is difficult to see how we could have achieved our present evolutionary position. In general, they fall into two groups—those which relate to our more recent human history and those which concern our prehuman development and emergence as man. Among the more prominent in the first group are our development of symbolic processes; the discovery of fire and of the wheel; and the slow coming together of animal husbandry, agriculture, and metal-working, to form a basis of the civilization we know today. These characteristics are so much a part of our life that it is difficult to realize that, in the time-scale of human evolution, they form a very recent acquisition. Figuratively speaking, they represent no more than the uppermost shoots of a tall and aged tree.

Our biologically unique characteristics enjoy a much greater antiquity. According to many authorities, the one which was most prominently concerned in our prehuman development, and without which we should not have evolved to the human level, is our dual possession of stereoscopic vision and fully opposable thumbs. This combination exists in no other animal. With it, the protohuman ape or monkey was able to explore and obtain increasing mastery over his external world, and because of the resulting interplay of tactile and visual impressions—so it has been argued—a simian brain finally evolved into the brain we possess. Compared with this, other biological characteristics that distinguish us from apes and monkeys are probably of small account. There is one, however, which was probably a critical factor during the period of our emergence as man. This is our unique diet. All apes and monkeys are predominantly, if not entirely, vegetarian. Man alone of the Primates is omnivorous.

If we had retained the Primate frugivorous habit, we should hardly have left the forests to which the gorilla, chimpanzee, orang, and gibbon are still confined by their dietary needs, and in the forests we should never have evolved as we have done. There is another side to this question. There is evidence that the forests of our forebears disappeared during a geological period of aridity, in the course of which it is believed we underwent the critical changes from an ape-like to a human form. It is not unlikely, therefore, that an omnivorous habit was actually forced on our ancestors by the gradual shrinkage of their natural food reserves, only those ape-men surviving and perpetuating themselves who succeeded in becoming adapted to a partly carnivorous diet—such as the cave-men of yesterday

enjoyed, and such as we still enjoy. Whichever way the change occurred, it is not difficult to see that it must also have been associated with major readjustments in family and social life.

The social unit in old-world monkeys and apes, and by inference presumably in the world of our forebears, is generally a polygynous and non-promiscuous family group which holds together as long as its male overlord remains sufficiently dominant to keep other males from, and to impress his own company on, his females. Internal familial relationships are largely determined by the sexual rhythms of the females, their alternating heat periods determining which is the favourite wife for the moment. Young can be born at any time of the year, but, so far as we can tell, the frequency of births shows marked seasonal variations. The family party grazes together, male, females, and young, all picking their own roots or fruits.

Familial relationships of this kind do not fit into a hunting economy, or a mixed hunting and food-gathering economy, of the type early man had to assume. Such an economy necessitates the sexual division of labour, since nursing and pregnant females and young could hardly join in the chase. With little doubt they would have stayed behind, collecting what roots and fruits grew around their homes, while their males hunted. Here, one is forced to another conclusion. Such a food economy is also hardly compatible with a polygyny sustained by male dominance. Since the sex ratio is to all effects equal, every polygynous unit means a number of roving unattached males waiting for the chance to break up a family when its overlord is away hunting. Slowly, natural selection must have worked on the conflict between sexual and nutritional drives, and monogamy must have become established as a disciplined habit of food-gathering and hunting peoples—as it remains today, so it is stated, among those of them who still survive in scattered parts of the world. If polygyny had continued through this phase of human history, it is difficult to see how the proto-human species could have avoided extinction through continuous familial disruption and internecine strife.

The topics that have been discussed so far are major issues in the story of our development which, at one time or another, have already excited the interest of students of human biology. In one sense, as has been suggested, they are no more than inferences from points of difference between us and the rest of the animal world. And, in another, they are no more than the statement of positive factors to which we can relate either the whole or part of our unique evolutionary development. None of them applies to the rest of the mammalian group to which we belong, and conversely it is difficult to recognize any characteristics peculiar to apes and monkeys which, had we possessed them, would have accelerated our own evolution. Indeed, in the more important biological equipment we improve on them every time. For example, our brains are basically—from the anatomical point of view—no different from theirs, but are very much better developed. Our hands are essentially the same, but being less evolved in certain directions, are more flexible in use. Our feet may be more specialized structures, and of no use as an accessory pair of hands, but conversely they are adapted to an upright attitude, which permitted the complete emancipation of our fore-limbs from their previous function as supporting and locomotor organs.

If it is difficult to recognize any sub-human Primate characteristics which would have accelerated our evolution, it is simple to see some which might have acted as obstacles to our development. Thus, there is one major difference of a negative kind between us and the rest of the zoological group to which we belong, and we can now see that this was probably as important to our evolution as any of the factors which have already been touched upon. It is our freedom from the rigorous internal chemical control of reproductive functions such as is experienced by apes and monkeys and even more so by other mammals. Recent research into the physiology and chemistry of the hormones which control reproduction—the hormones of the anterior lobe of the pituitary gland, and the steroid hormones of the gonads—shows that this freedom must have been vital to our emergence as *Homo sapiens*. Let us look at the question more closely.

The rhythm of life in most wild animals is rigidly fixed by the periodicity of the reproductive processes. Thus, the migration of birds is ruled by fluctuations in the bodily concentrations of the steroidal hormones produced in the gonads, and these fluctuations are, in turn, determined by seasonal variations in the degree to which light stimulates the anterior lobe of the pituitary gland to produce its gonad-stimulating hormones. If a bird which is about to set out on its southward flight as the autumn approaches is caged for a sufficient period for its reproductive organs to

regress to the non-breeding state, it will make no attempt to migrate when it is released. The motivating power, or drive, provided by its sex-hormones is no longer there.

Similarly, the entire life of most mammals is constrained by the periodic functioning of the sex organs. Thus, while the geographical areas in which most wild mammals are found are fixed by general selective processes, for example nutritional needs, their major movements within these areas are directed by the internal motivating forces, if they can so be called, which vary according to fluctuations in, and changes in the nature of, the sex-hormone content of their bodies. Thus the fighting of stags in the early autumn; their subsequent mating with the hinds; the formation of polygynous family parties sustained by male dominance; the breaking away of the unmated males; and, when the mating season is over, the separation of males and females until next year's season approaches, depend for their motivation entirely on these sex-hormones. The worlds of such animals, already restricted to their immediate environment and immediate present, are thus rigidly determined by an internal chemical control, whose bonds cannot be broken. What they do next, and their social relationships, are both preordained.

This internal chemical control is not as strict in the world of apes and monkeys, but, so far as is known, it is still sufficiently powerful to dominate the social lives of almost all species. As in the case of the Red Deer, the geographical areas in which monkeys and apes live are determined by general selective processes. On the other hand, although their birth-rate shows marked seasonal variations, sexual activity is not confined to a restricted season, and consequently male and female monkeys and apes are always together. Their social unit, however, as has already been mentioned, remains in general the polygynous family party sustained by masculine dominance. This can be taken as representing the operation of a powerful masculine sex-drive—a drive at least partly determined by the concentration of male hormones in the body. Furthermore, relationships of the females to the males within each family unit, and of the females to each other, are controlled by the alternating periods of heat of the females. These reflect phases of elaboration and concentration of gonadal sterol hormones, and in many species are associated with very prominent changes in the appearance of the body. A female in heat appears to dominate masculine interest and, at the same time, is very strongly attracted to the male. Her sexual dominance affects all members of the family party of which she is a member. In this way, a rigid chemical control of social relationships delimits the bisexual social world of the ape or monkey.

From all this man has been freed. Had so rigid a mechanism operated in the period of our emergence, the proto-men could hardly have undergone either the ecological change in food habit which ensured human survival or, what we may now be permitted to regard as the first major social revolution of our species, the stabilization of the family unit. The inference that such a change must have occurred suggests that the motivation provided by male sex hormones was not strong enough to prevent the first men from abandoning, at least overtly, the full exercise of polygynous tendencies. Furthermore, it is a safe assumption that the rhythm of sexual impulse was probably very much weaker in the first women of our species than it is in existing apes or monkeys, or than it probably was in our ape-like forebears. Had these things been otherwise, personal relationships would have been too confined by internal chemical control to permit the social changes necessary to our survival and social evolution.

But very obviously they were not confined. Instead, by means of the symbolic processes we have developed, we have been able to reach out to a mastery of our external world, a mastery extending far beyond the confines of our immediate environment, and a mastery which also frees us completely from the confines of a restricted geographical orbit. But in our freedom from a predetermined and hormone-determined framework of social relationships, we are at a disadvantage in other ways, in particular because of our failure to come to any agreement about the shape human relationships should take. Major differences of opinion on this problem have resulted before, and now result once again in this war, in violent intraspecific struggles. If the major biological steps in our social evolution have been correctly read, similar struggles had to be overcome at another very dangerous period of our evolution, the time of our emergence from the ape world.

Another disadvantage of our relative freedom from sex-hormone control has a more individual character. The association of human evolution with the abolition of a clockwork reproductive system finds us today in possession of a system

which, quite apart from the fact that it can be very easily checked by individuals anxious not to breed, not uncommonly breaks down physiologically.

For lack of evidence to the contrary, the decline in the birth-rate which is now occurring in most countries is not generally ascribed, either in part or as a whole, to physiological causes—although it can of course be said that were the internal chemical control of human reproduction stronger and more clock-like in its action, it would be more difficult to check reproduction than in fact it is. The general problem is, however, so important that the possibility that physiological factors do help in producing today's widespread picture of sterility urgently requires investigation. Associated with such an inquiry we also need more intensive research into the physiology and chemistry of the endocrine system in general, and of the sex-hormones in particular. Quite apart from the wider problem of population growth and decline, only such research can help the more easily recognized cases where the human reproductive machine breaks down for definitely physiological reasons. We might almost say that, if the emergence of man was related to a partial emancipation from a predetermined control exercised by these hormones, the well-being of its future will undoubtedly be assisted by a rational control of reproductive and endocrine derangements. For this, much more knowledge is wanted than we yet possess.

Book reviews

DETECTION OF RADIO FAULTS

Testing Radio Sets, *by J. H. Reyner. Pp. viii + 215. Chapman & Hall Limited, London. Fourth edition, revised,* 1943. 15*s. net.*

In testing a radio set an orderly approach to the task is essential, but slavish adherence to a routine will often result in an effect passing unnoticed or, at least, remaining undetected until many of the tests have been repeated. The author of this excellent book pays due attention to instilling an appreciation of the principles underlying the various tests.

Just sufficient of the functioning of the circuits and components is explained to make performance-checking and fault-finding a process of straightforward deduction, as far as is possible with the wide variety of designs which is likely to be met.

A useful feature is the treatment of variations in design, with special reference to their effect on irregular behaviour of equipment. The beginner will find the hints on the best arrangements for wiring worthy of attention.

The chapter on unusual faults leaves the reader in the right frame of mind to do some real detection when normal methods fail to reveal the cause of the trouble.

Anyone requiring guidance in testing radio sets will find Mr Reyner's book most valuable. It is characterized by clarity of explanation and a minimum of mathematics.

WEATHER WISDOM

The Weather, *by George Kimble and Raymond Bush. (A Pelican Book.) Pp.* 188. *Penguin Books Limited, Harmondsworth and New York.* 1943. 9*d. net.*

It is not an easy task to present a highly technical subject in a way that will appeal to the ordinary reader, but the authors of this book may fairly claim to have achieved it. Within its 188 pages there is a wealth of information about weather phenomena, all very simply expressed; and the reader who is of an inquiring turn of mind will find lucid explanations of the physical processes which underlie the changes in our weather.

The numerous references to weather lore are particularly interesting, and the authors are able to show that the 'Shepherd of Banbury' is frequently supported by both fact and theory; on the other hand, they condemn in no uncertain terms such apocryphal instruments as the 'storm glass' and astrological portents like 'the moon lying on her back.'

It is to be hoped that readers who follow the suggestion of becoming their own single-observer forecasters will not expect too high a proportion of successes. Subject to this proviso, there is much to be said for the idea. The making of your own observations is in itself an excellent habit, whilst the failure of even the most confident of your own forecasts may make you a trifle less critical of the professional forecaster's lapses! N. K. JOHNSON

A SURVEY OF INORGANIC CHEMISTRY

Inorganic Chemistry, *by Fritz Ephraim. English edition by P. C. L. Thorne and E. R. Roberts. Fourth edition. Pp. xii +* 921. *Gurney & Jackson, London.* 1943. 28*s. net.*

The progress of inorganic chemistry is epitomized in a comparison of the four editions of this book. Unique among textbooks of inorganic chemistry in its conception and planning, the first edition in 1926 went far in its attempt to present an adequate and at the same time coherent survey of the facts of inorganic chemistry. Since that date the rapid progress in knowledge of atomic structure and the development of clearer ideas of the nature of atomic bonds have made possible a more compact and logical treatment of the chemistry of inorganic compounds.

This progress is reflected in the changes that have been made in the earlier parts of this edition, and the reviewer finds in the first three chapters an admirable and concise summary of present knowledge of atomic structure, of valency theory, and of methods of determining molecular structure.

The remaining chapters of the book have been fully revised in the light of this knowledge, and wide use is made of the more intimate picture of molecular structure provided by X-ray crystal studies, by electron diffraction, and by dipole moment measurements.

In revising the factual matter,

judicious selection has been shown in the accounts of recent work that have been included, and the gain in material has been achieved without sacrifice of the essential cohesion of the treatment. Every student of chemistry will find this new edition helpful and stimulating; its production is a triumph in war-time conditions. No other book, within such a compass, presents so satisfactory a survey of the field.

F. G. TRYHORN

FAT METABOLISM IN ANIMALS

The Metabolism of Fat, *by Ida Smedley-MacLean. Pp. vi + 104. Methuen & Company Limited, London.* 1943. 4*s. net.*

This excellent little book gives a summary of present knowledge concerning fat metabolism in animals and in isolated animal tissues. It is most useful for both student and teacher, and is supplied with an adequate number of references to the most significant literature. Results of modern methods of attack on the problems of fat metabolism, such as those obtained with the use of radioactive phosphorus or heavy hydrogen, or with the employment of the tissue-slice technique, are discussed. Chapters in the book are devoted to the subjects of the mode of synthesis of fatty acids in the body, of the constitution of the natural polyene unsaturated acids and the part they play in fat metabolism, of the modes of combination of fatty acids in the body, of the methods of absorption and transport of fats in the body, and of the modes of fatty acid oxidations. The book is well written and the subject-matter is critically presented.

J. H. QUASTEL

IDENTIFICATION OF DISEASE-BEARING INSECTS

A Handbook for the Identification of Insects of Medical Importance, *by John Smart and others. Pp. x + 270, with 13 plates. British Museum, London.* 1943. 15*s. net.*

Few aspects of animal biology have shown more rapid growth than medical entomology. From the zoological standpoint new knowledge is continually being added concerning the species of insects that are vectors of disease. At the same time, medical workers are adding to the fund of information bearing on the pathogenic agents concerned and on methods of preventing or curing their effects. It is rarely that these two aspects of a great subject are adequately combined in a single textbook, and the rapid growth of medical entomology renders this synthesis increasingly difficult to attain. Dr Smart's volume is essentially a zoological treatise. It is concerned with the identification of all Old World species of insects known to be of significance in medicine and hygiene. The importance of accurate identifications is paramount, for one species of insect may be a proven disease vector and a closely allied species may be totally harmless. Wrong identification of a species of *Anopheles*, for example, is likely to render attempts at malaria-control unavailing. In the literature of medical entomology there are numerous cases of misidentification. In the present book only an elementary knowledge of entomology is assumed, but we anticipate that little difficulty will be found in following its tables and descriptions. These are clearly drawn up and accompanied by an excellent series of illustrations. In a work of this kind the Diptera naturally call for the most extended treatment. In addition to keys for the identification of the adults, there are useful synopses for the recognition of myiasis-producing larvae and of the fourth-stage larvae of *Anopheles* affecting different regions of the world. The Siphonaptera, or fleas, come in for very full treatment by Dr Karl Jordan, and Mr R. J. Whittick contributes a useful chapter on Arachnida. The authors and the Trustees of the British Museum are to be congratulated on having produced a thoroughly sound and up-to-date volume. Its exceptionally low price, as judged by present-day standards, is a further commendation.

A. D. IMMS

THE OUTLOOK FOR WOOL PRODUCTION

The Future of Wool, *by Pablo Link. Buenos Aires.* 1943. *N.p.*

An analytical survey of wool production in the Argentine illustrated by details of the wool and sheep production in the different provinces. Since 1895 there has been a steady increase in numbers of sheep in Patagonia, while individual fleece-weights have increased from 6 lb. to 8¼ lb. The wool consists mainly of fine to coarse crossbred types. An attempt is made to forcast the future of wool in post-war years by considering the general trends in the textile industry. While the consumption of some textiles has increased more than that of others during the last thirty years, the *per capita* consumption of wool has increased by 20 per cent. Because of the difficulty of producing artificially a cellular tube which felts like wool, it is considered unlikely that the synthetic wools which have been produced will be suitable for cold climates. It is concluded that both cotton and wool have increased, and will increase, in consumption without interfering with one another. There has been a decrease, and as a result of the war there will be a further reduction, in European wool production, so that wool in large quantities will be required in the future.

PETROLOGY OF IGNEOUS ROCKS

Eruptive Rocks, their Genesis, Composition, and Classification, *by S. J. Shand. Pp. xvi + 444, with 3 plates. Thomas Murby & Company, London; John Wiley & Sons Inc., New York.* 1943. 25*s. net.*

The appearance of the second edition of Professor Shand's stimulating textbook will be welcomed by many geologists. The book was first published in 1927, and opportunity has been taken to make a complete revision and to add more than 80 pages. This has made it possible to include new chapters on the order of crystallization of minerals, compatible and incompatible phases, and eruptive rock complexes, but in addition there is a much more extensive discussion of recent petrological literature. A wide range of references following each chapter is a valuable feature of the book.

The account of the physical chemistry of the igneous rocks presents the more important aspects of the subject in such a way that it will form a suitable introduction to this subject for other readers whose main interest in not in petrology. After a discussion of the problems of classification, eight subsequent chapters are devoted to the more detailed description of the igneous rocks. The final chapter deals with meteorites, and leads to the consideration of the 'pregeologic' history of the earth.

The volume is well illustrated, splendidly produced and, apart from some delay in its publication, does not appear to have suffered seriously from war-time conditions.

A. E. TRUEMAN

Notes on contributors

JOHN READ,
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Was born in 1884 and was educated at Sexey's School, Bruton, Finsbury Technical College, and the Universities of Zürich, Manchester, and Cambridge. Lecturer and Demonstrator in Chemistry at Cambridge from 1908 to 1916, he was in the latter year appointed to the chair of Organic Chemistry, Pure and Applied, in the University of Sydney, Australia. After seven years of distinguished research, administrative, and teaching work, he was in 1923 elected to his present post of Professor of Chemistry and Director of the Chemistry Research Laboratory in the University of St Andrews. He has published numerous original memoirs on the chemistry of the essential oils and other natural products, on the menthone series, and on many branches of stereochemistry. He is also known as an able expositor and historian of his subject, and in his recent book on *Explosives* successfully explained to the general public the principles of an abstruse branch of applied chemistry. He was elected F.R.S. in 1935.

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Major-General M. N. MacLeod was born in India in 1882, but came to England at the age of 5. He was educated at Rugby School and the Royal Military Academy, Woolwich, from which he passed out first, gaining the Pollock and Queen Victoria gold medals and the prizes for military topography and geometrical drawing. He was commissioned in the Royal Engineers in 1900, and served in India from 1902–14—with the Military Works Services for the first two years, but afterwards with the Survey of India. During the war of 1914–18 he served in Belgium, France, and Germany in command of the 145th A.T. Company, R.E., and later of the 4th Field Survey Battalion. From 1919–23 he was Chief Instructor, School of Artillery, Salisbury, subsequently joining the Ordnance Survey, of which he became Director-General in 1935. He was A.D.C. to the King from 1936–39.

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Was born in 1889. He was one of the late Lord Rutherford's earlier students at the University of Manchester, and his interest in atomic physics dates from that time. After acting as Lecturer and Assistant Director of Physical Laboratories at Manchester, he became successively Reader and Carnegie Teaching Fellow at the University of Edinburgh and Professor of Physics at University College, Cardiff. Since 1930 he has been Professor of Physics at Queen Mary College, University of London. During the war of 1914–18 he held a commission in the Royal Artillery (but was attached to the Royal Engineers) and served in France. He has published many original papers, mainly on radioactivity, Röntgen rays, and atomic structure. He says he has the normal interest of his kind in food, drink, and old scientific books, and for a time he was a Governor of the Vic-Wells Theatres.

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Born at Cape Town in 1904, he was educated in South Africa and then at University College Hospital, London. From 1928 to 1932 he was Research Anatomist to the Zoological Society of London, a post which enabled him to extend his researches, begun in South Africa, on the anatomy, physiology, and behaviour of monkeys and apes, with particular reference to questions of human evolution. Certain of these studies formed the basis of his books entitled *The Social Life of Monkeys and Apes*, published in 1932, and *Functional Affinities of Man, Monkeys, and Apes*, published the following year. His researches then became directed to the question of the hormonal control of reproductive processes in monkeys and apes, and from this to a more general study of the action of hormones and of their influence on various growth-processes and reproductive mechanisms. This work was begun in 1933 during a period spent at Yale University in America, and has been carried on since 1934 in Oxford, where he is on the staff of the Department of Human Anatomy.

In 1939 he was appointed to the Chair of Anatomy in the University of Birmingham, but war duties, which began with a study of the biological effects of explosives, have so far prevented him from taking up this appointment.

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